MILITARY GEOLOGY OF OKINAWA-JIMA, RYŪKYŪ-RETTŌ

VOLUME II WATER RESOURCES

by
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FOREWORD

Engineer Intelligence Study - Okinawa-jima, Ryūkyū-rettō

The Military Geology of Okinawa-jima, Ryūkyū-rettō is one of a series of reports resulting from detailed geologic and soil surveys conducted under the Pacific Geological Mapping Program. The purpose of the surveys is to produce information on the military geology of selected areas of the Pacific by field mapping and analysis of selected islands.

The Military Geology of Okinawa, includes separate sections on Engineering Aspects (Vol. I), Water Resources (Vol. II), Cross-country Movement (Vol. III), Soils (Vol. IV), and Geology (Vol. V), of which this is Volume II.

This study was prepared in cooperation with the U. S. Geological Survey, Department of the Interior.

PHILIP F. KROMER, JR.
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MILITARY GEOLOGY OF OKINAWA-JIMA, RYŪKYŪ-RETTŌ

VOLUME II. WATER RESOURCES

by Cornelia C. Cameron, Delos E. Flint, and Raymond A. Saplis

Introduction

Purpose

This report presents a summary of the water resources of Okinawa-jima with special emphasis on the densely populated southern part of the island (fig. 1). Its purpose is primarily for use in planning. This report is not intended to take the place of field investigations for water development at specific sites.

Background information

This report is based on geologic mapping of Okinawa carried on 1946 to 1949 by a U. S. Geological Survey field party, led by Delos E. Flint, as part of the Pacific Island Mapping Program, and a survey of water resources conducted by Cornelia C. Cameron, geologist, during the first three months of 1957 at the request of the Engineer, U. S. Army, Ryukyu Islands and IX Corps.

Data are included from: the Office of the Post Engineer, U. S. Army, Ryukyu Islands, especially the Sanitation Section; the District Engineer, U. S. Army Engineer District, Ryukyu Islands; the U. S. Navy, the U. S. Marines, and the U. S. Air Force on Okinawa; the U. S. Civil Administration, Ryukyus; the Government of Ryukyu Islands, particularly from Mr. Wauke, Civil Engineer Section, Public Services Department and Mr. Wakajima, Land Development Section concerning springs and wells in southern Okinawa; and Okinawa well drillers and owners, especially Mr. Kuwae, manager of Kokuei Kan Theater, Naha, who provided information on several of the deep wells in and near Naha, Yonabaru, and Katchin-hantō. Reports of D. J. Cederstrom and F. A. Swenson, ground-water geologists who accompanied U. S. Forces during the military operations on Okinawa in World War II, contributed data.

Summary Evaluation of Water Resources

Water resources in general are abundant on Okinawa, but locally the sources of water are small and show marked seasonal variation. The northern part of the island has large quantities of surface water most of the year. In the southern, heavily populated part, only moderate to small quantities of both surface and ground water are available throughout most of the year (pl. 1, Ground-water map and pl. 2, Surface-water map).

In southern Okinawa the main sources for the Integrated Island Water System are the Bishi-gawa and Tengan-gawa. Springs, a few deep wells, and small streams contribute only about one-eighth of the total water treated by this system which supplies many military installations in the southern part of the island. The Chinen Treatment Plant, an independent unit, is the only military plant which draws entirely from a spring. Military installations in northern Okinawa obtain most of their supplies from streams.

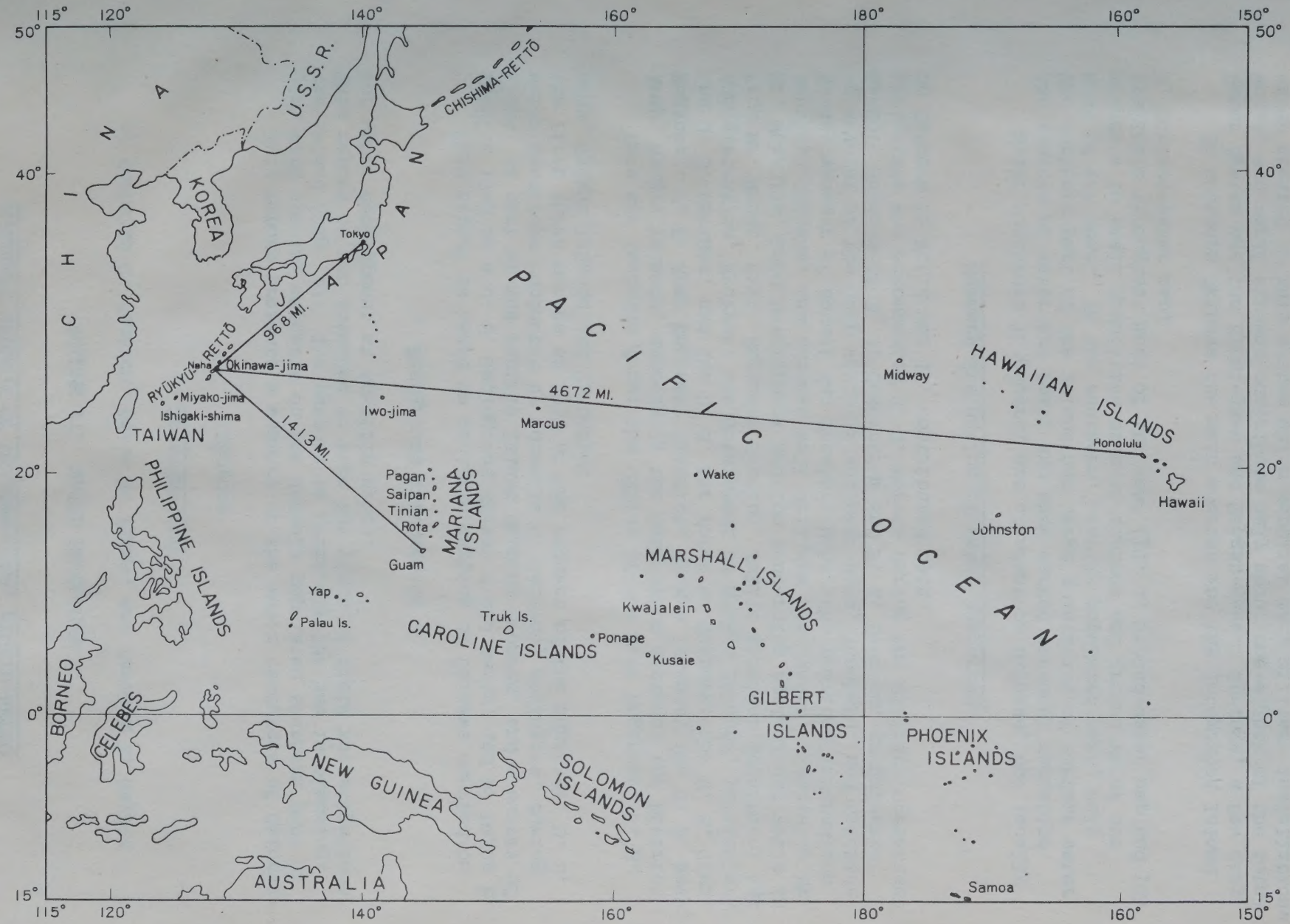

Figure 1. Index map of Okinawa-jima, Ryūkyū-rettō.

Local water supplies for native domestic use in southern Okinawa are obtained largely from springs and shallow wells dug in limestone to the top of the underlying Shimajiri clay, in local fine sand beds of the Shimajiri formation, in stream alluvium, and in beach deposits. The Naha City Treatment Plant draws water entirely from springs. Quantities are generally small and fluctuate seasonally. During dry periods the Naha City Treatment Plant, which is tied to the Integrated Island Water System, is supplied in part by military sources.

Okinawans in the northern part of the island depend primarily upon streams to supply water for domestic and irrigation purposes.

Northern Okinawa is generally well suited for the development of surface-water resources. Six basins north of Motobu-hantō are drained by streams with a discharge of more than 5,000,000 gpd (gallons per day). The Bishi-gawa and Tengan-gawa to the south also have discharges of more than 5,000,000 gpd, but farther south surface water is more scarce. The largest streams in southern Okinawa include four draining to the East China Sea and one draining to the Pacific Ocean. They discharge between 1,000,000 gpd and 5,000,000 gpd at high stage. Most of the other streams fail during periods of drought and in many parts of southern Okinawa, drainage is largely subsurface.

Most of southern Okinawa is unsuited for the development by wells of sources of ground water for large military and municipal water systems. The most suitable areas are a small area between the Easley Treatment Plant and the town of Kin, and a belt extending from Tengan Treatment Plant through Napunja and Tybase Treatment Plants to east of Highway 1. At least 200,000 gpd are available from single wells drilled in limestone and limy sand and gravel to depths ranging generally from 90 to 100 feet. The wells are used to supply the Napunja Treatment Plants and by the Air Force for washing vehicles and airplanes. This belt contains a minimum potential of 4 or 5 million gallons per day of fresh, very hard, unpolluted water which could be obtained by a field of properly sited and developed wells.

Some areas of limestone near the coast cannot be expected to produce more than 75,000 gpd from single wells with bottoms at or below sea level without danger of salt-water intrusion. This danger has been demonstrated by the well supplying the Yontan Treatment Plant. Elsewhere in limestone 10,000,000 gallons per day or more of fresh water might be obtained from a single well with bottom on Shimajiri clay above sea level. The chance of obtaining such a well is remote, since success of well drilling in such areas depends upon the fortuitous tapping of trunk solution channels fed by many tributary channels.

Most of the areas of the Shimajiri formation will produce dry holes except locally where the formation is a fine sand. Single large-diameter wells in such places will generally yield less than 30,000 gpd.

The area at the head of Kokuba bay and to the southeast is an outstanding exception because potable artesian water for agricultural and industrial purposes has been obtained at depths of 250 to 500 feet from sand and gravel at or near the base of the Shimajiri formation. The water is artesian in that it rises to or almost to the surface. The potentialities of this region should be explored because it is easily accessible to Naha city and adjacent towns.

Variable quantities of fresh water may be obtained from shallow dug wells and infiltration galleries in alluvium and beach deposits. Yields will generally be small, but a few wells will produce as much as 100,000 gpd.

Within the areas of Paleozoic rocks, in northern Okinawa, the best wells are located in hard-to-find fracture zones, but they cannot be expected to yield more than 10,000 gpd. The abundance of surface water north of the latitude of Katena (Kadena) makes development of wells or springs unfeasible unless small amounts are required locally.

All surface and ground water on Okinawa must be treated for bacterial pollution before drinking. The Okinawans make use of human excrement as fertilizer. This practice causes the spread of parasites and disease germs to streams and also to springs and shallow wells through the movement of ground water. Bacterial contamination in densely populated southern Okinawa is greater than in the northern part of the island where there are fewer cultivated fields, but considerations of safety require the treatment of all water even where obvious sources of contamination are lacking.

Flash high turbidities in surface streams and some springs follow heavy rains; therefore, coagulation with alum before filtration is necessary.

The water in the limestone areas, principally in southern Okinawa and Motobu-hantō is very hard. The hardness is due largely to calcium bicarbonate ($Ca(HCO_3)2$) which comes mainly from the weathering of the limestone. The hardness makes the installation of local water softening units desirable for laundries, boiler plants, hot-water heaters, and engine-cooling systems to avoid deposition of scale. However, the water is not so hard that the installation of softening equipment is required in military treatment plants.

Analyses of raw water show the effect of the different kinds of rock aquifers and stream beds upon the chemical composition of the water. Water from sand at or near the base of the Shimajiri formation is distinctly different in composition from any other water in Okinawa. It tends to have a low total hardness but a high total solid and chlorine content. It ranges from potable water to brackish water associated with natural gas. Water from the Paleozoic sandstone, schist, and phyllite of northern Okinawa is potable, soft to moderately hard, and very corrosive.

Factors Influencing Water Resources

Climatic aspects

Records kept over long periods indicate that on the average Okinawa has a plentiful rainfall (fig. 2). In spite of this fact, the amount of rainwater contributed to the surface- and ground-water resources is comparatively small. This is because much of the rain falls in torrential showers during storms which pass in an hour or so. As a result runoff is very rapid. Streams of the small drainage areas which are affected by the showers rise in flash floods of highly turbid water. The areas of overflow are usually small and restricted to the immediate vicinity of the streams.

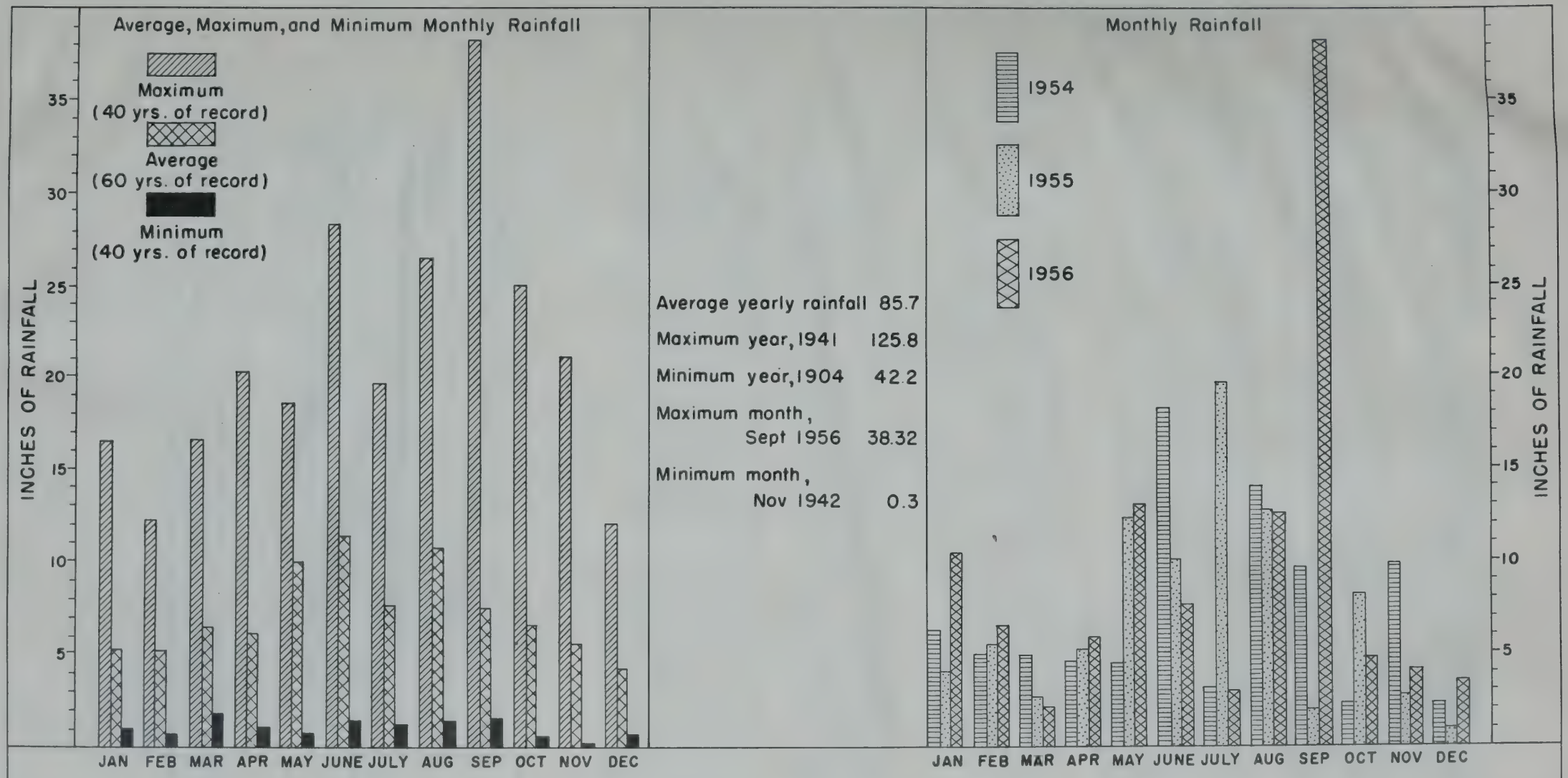

Figure 2. Comparative monthly rainfall data.

Data are from observations at Kadena Airbase and from Okinawa weather reports.

The most widespread and serious floods are those caused by the typhoons characteristic of summer and autumn. During a single typhoon more than 20 inches of rain may be released during a 24-hour period.

The average yearly rainfall, measured at weather stations in southern Okinawa over a 60-year period, is 85.7 inches. There is, however, a considerable difference between the average annual rainfall and maximum and minimum annual rainfalls. The wettest year was 1941 with 125.8 inches. The driest year occurred in 1904 with 42.2 inches.

Average, maximum, and minimum monthly rainfall figures show even wider variations than the annual figures. During the past 60 years, December has been the driest month with rainfall averaging 4.2 inches, but December has had as little as 0.9 inches and as much as 12.0 inches. June, with an average rainfall of 11.3 inches, is the wettest month, but its minimum rainfall has been 1.3 inches and its maximum rainfall 28.3 inches.

The records of monthly rainfall measured at Kadena Airbase January 1954 through December 1956 show the type of departure from the average monthly figures that should be expected for any given year. Of special interest is the month of September with 1.9 inches of rainfall in 1955 and 38.32 inches in 1957. The average rainfall for September, over a period of 60 years in the Naha area, is 7.4 inches.

During September and October 1947 less than 2.5 inches of rain fell at Kadena Airbase and low rainfall was also typical of March, July, and November, 1948. Less than 2.5 inches were recorded for each of these three months. If these normal rainless periods had been extended further water supplies would have been greatly diminished.

There is also much variation in rainfall from place to place on Okinawa as shown by the records of average annual rainfall measured at each of 15 weather stations on the island (fig. 3). For example, the figures for Naha may be higher than those for many other parts of Okinawa. There appears to be no overall geographic control of the amount of rainfall. Instead, abrupt changes in local relief seem to be the controlling factor.

Geological aspects

Okinawa is divided geologically and topographically into two distinctly different provinces, each with its typical hydrological characteristics. North of the Ishikawa isthmus of the island, numerous short valleys are deeply incised in elevated terraces. Many streams have their headwaters in the high, rugged, tree- and shrub-covered mountains that comprise the backbone of the northern two-thirds of the island. Most rocks in this severely dissected topography are sandstone and foliated metamorphic rocks of the schist and phyllite variety; all of these rocks were formed during the Paleozoic era of geologic time. Terrace remnants are capped by sandy, clayey gravel. Only near their mouths are the larger streams alluviated.

Areas of limestone, formed during the Paleozoic era of geologic time, in which drainage is subsurface occur on Motobu-hantō and on the northern tip of Okinawa. Coralline and rubbly limestone, formed during the much younger Tertiary and Pleistocene geologic ages, fringe the coast locally.

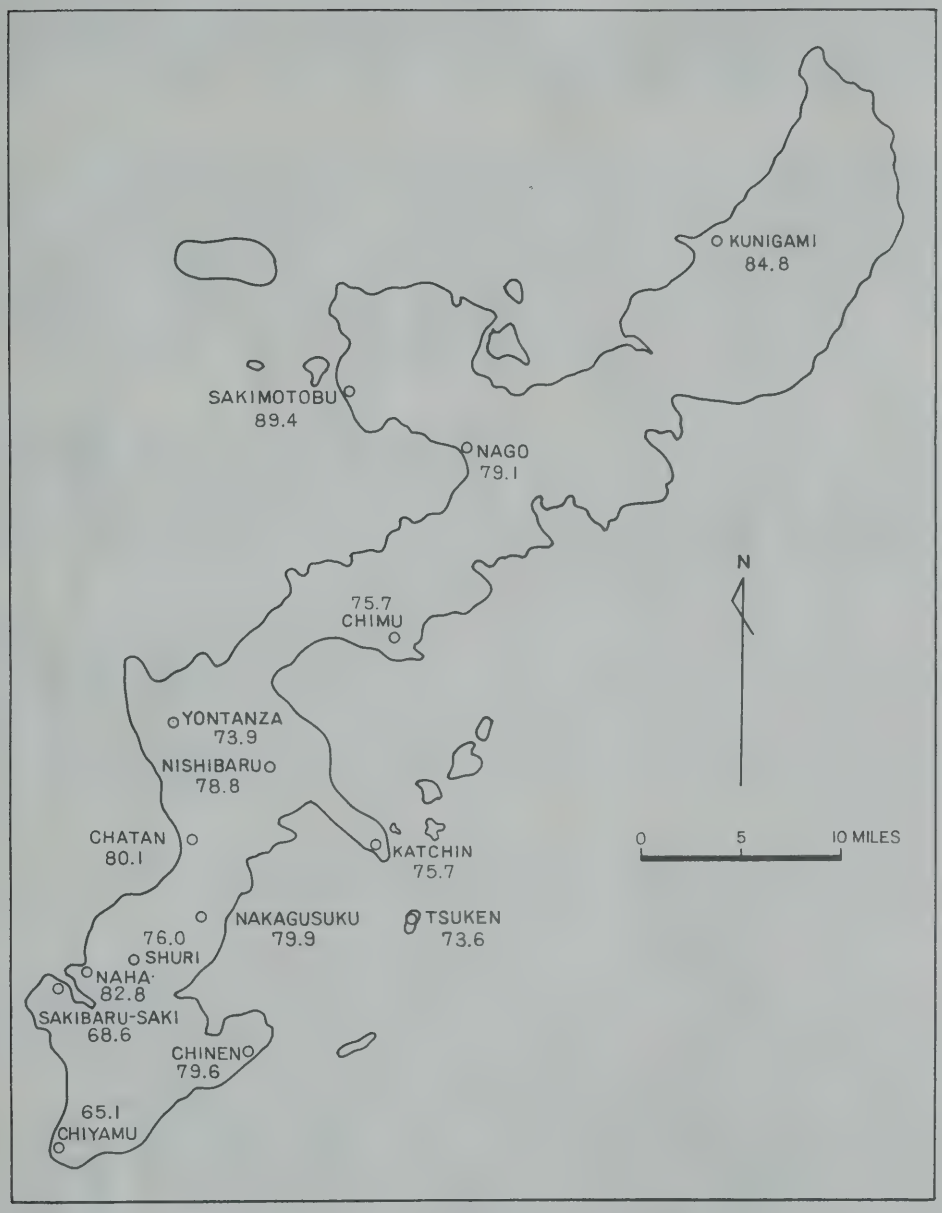

Figure 3. Mean annual rainfall in inches at fifteen weather stations on Okinawa. Data from U. S. Navy Dept., Civil affairs handbook Ryukyu (Loochoo) Islands, OPNAV 13-31, p. 8-9, 15 November 1944.

The topography south of Ishikawa consists mostly of broad low valleys and broad upland plateaus rimmed by steep scarps. Wide expanses of Tertiary and Pleistocene limestone, broken by limestone ridges, knobs, and pinnacles, are extensively developed northward from Camp Kue and around the prongs of Paleozoic highlands that extend only as far south as Kadena Airbase. The southern end of the island is dominated by two limestone-capped plateaus broken by steep cliffs and rough ridges. The sea in most places is bordered by narrow alluvial plains backed by sea cliffs. The limestone flanking the west coast is cut by vertical-walled canyons, but where the streams cut back into the Shimajiri formation of clay, silt, and fine sand the topography takes on badlands aspects. The topography is generally more rounded, however, in the narrow waist at Yonabaru.

The upland surfaces in southern Okinawa slope gently seaward from an elevation about 350 feet above sea level. The interior of the island south of the base of Katchin-hantō is composed of the relatively impermeable Shimajiri clay, silt, and fine sand. The Shimajiri formation is overlapped on the west and at the north and south ends by very permeable limestone beds. The much older Paleozoic metamorphic and igneous rocks of northern Okinawa are buried deeply beneath the Shimajiri formation in the south.

Numerous high-angle faults slice the island roughly perpendicular to the axis of the anticline, or fold that is convex upward, which trends roughly northeast-southwest. Many springs and seeps mark the faultlines where the impermeable clay is brought up against the permeable limestone.

In sharp contrast to northern Okinawa, southern Okinawa south of the Bishi-gawa and Tengan-gawa has poorly developed surface drainage. Drainage is primarily subsurface in limestone areas of karst topography With few exceptions streams in the areas of Shimajiri compact clay and silt are short and intermittent. The areas also generally lack subsurface drainage.

Water Supply Systems and Treatment Plants (1957)

Okinawa water-supply systems

Before the military campaign of 1945 an extensive water distribution system served about 4,000 outlets in the metropolitan area of Naha. Water was collected from 12 springs and streams between Machinato and Futema-gawa and piped, by gravity flow, to a pumphouse located near the mouth of Machinato-gawa. Two large reservoirs, one near the treatment plant and one on the hill to the south of Naha, stored the water for distribution through the city's mains. This system furnished a reported 1,800,000 gallons of water per day to the metropolitan area of Naha. During and after the fighting of 1945, the system was destroyed in large part and the remainder badly damaged. Major repairs, amounting essentially to reconstruction, were made in 1953 to put this system back into operation. The new Naha City Treatment Plant was tied to the U. S. Military's Integrated Island Water System (pl. 1).

Raw water from five springs, S-12, S-37, S-39, S-42, and S-43, is piped into the city's Machinato Pumping Station and delivered from there to the treatment plant through a single 14-inch, 22,000-foot

pipe. The piping system and plant have a maximum capacity of 3,100,000 gpd. The treated water passes from the plant to an adjacent clear-water reservoir of 1,000,000-gallon capacity which feeds directly into both the city's distribution system and into a 14-inch pipe connected to a 750,000-gallon reservoir located adjacent to Naha Airbase. The distribution system provides water to the Shuri, Mawashi, and Sobe suburbs as well as to Naha proper.

The present demands on the Naha City Treatment Plant and Water System have averaged 2,000,000 gpd and approached 2,600,000 gpd during the summer of 1956. Naha City Water Works officials anticipate that during the summer of 1957 the demand will approach 3,000,000 gpd and by the summer of 1961 the requirement will be 5,400,000 gpd.

Since the sources of raw water for the Naha City Treatment Plant diminish to 900,000 gpd in the dry season, it is the present practice to supplement plant production with water from the military system during the dry spells. The amount of supplementation to date has varied between 200,000 gpd and 1,000,000 gpd which approaches the limit of what the military can spare.

There is a very critical need for adequate water supply to meet Koza municipal requirements. Koza city has completed plans for a municipal water treatment plant which will take approximately 1,500,000 gallons of raw water from the Shinakawa-gawa, a tributary of the Bishi-gawa. This is the same stream used as the raw-water source for the Jaku Treatment Plant belonging to the Integrated Island Water System. The Koza city officials plan to break ground for this project on or about 1 July 1957 at a location approximately 2,000 feet in a northerly direction from the intersection of Highways 13 and 16 (P-8, table 1 and pl. 2, Surface-water map).

Supply for domestic use is obtained largely from local sources including streams, wells, and springs (pl. 3). No attempt is made to protect the purity of these sources. In a few localities water is piped from springs and streams to distributing points centrally located in nearby villages. The city of Nago in northern Okinawa has the best distribution system of this type. Usually most water-supply systems are short and few of them use pumps. Irrigation systems, however, tend to be somewhat more elaborate, and aqueducts up to many miles long bring water from mountain streams down to the paddy fields and gardens on the fringes of the island.

Village groups commonly dig wells and infiltration galleries and improve springs to serve as water points for the householders of the district. Family groups also dig wells in the yards of their homes, and neighbors often draw water from the completed wells. An example of how some Okinawans utilize wells for irrigation is shown in Plate 4.

Military water-supply systems

The Integrated Island Water System: The major system serving military installations in the southern part of Okinawa is the Integrated Island Water System. Pipelines extend along the west side of the island from Yontan Treatment Plant in the north to Yuza Treatment Plant in the south. Pipelines on the east side extend from the Tengan Treatment Plant to the tip of Katchin-hantō. Other extensions connect Tengan Treatment Plant with the interior and the west. Eight treatment plants

Table 1. Dams, dam sites, and surface-water intake points

Locations of points listed here are shown on Plate 1, Ground-Water Map. The coordinates are Universal Transverse Mercator grid references and may be found on AMS L791, Ryūkyū-rettō, 1:50,000. Numbers in parentheses refer to drainage basin numbers as used on Plate 2, Surface-Water Map and Table 3, Description of Drainage Basins.

Number	Name or Location	Coordinates	Source	Geological Conditions	Comments
P-1	Intake point for Okuma Treatment Plant. Intake is E of Highway 1 and S of Okuma.	DE 178562	Stream with 6.1 sq mile drainage area. Flow of stream exceeds 5,000,000 gpd (gallons per day) at high stage; does not go dry. Less than half the flow is diverted to flood paddy fields.	Most of the basin (14) is underlain by Paleozoic phyllite, sandstone, greenstone, and limestone. Surface drainage is developed throughout most of the area; some subsurface drainage occurs near the basin mouth.	Okuma Treatment Plant is located at the Military Rest Center approximately DE 167566. Design capacity is 140,000 gpd. Clear-well capacity is 15,000 gpd. The spring formerly used goes dry and was abandoned as the source of water for the Okuma Treatment Plant.
P-2	Intake point for Easley Treatment Plant.	CE 911275	Reservoir with capacity of 93,000 cu ft. Constructed by the Japanese about 1917 for sugar cane irrigation.	The reservoir is on Paleozoic sandstone not far from very much younger sandy limestone and gravel.	Easley Treatment Plant is located at the west end of Chimmu Airfield approximately CE 918262. It has a design capacity of 100,000 gpd.
P-3	Site for construction of the Camp Hansen dam.	CE 936271	The stream has a drainage area of 5.2 sq miles.	The dam will be constructed on Paleozoic phyllite and sandstone. Most of the reservoir will be underlain with relatively impermeable Paleozoic rocks, but is margined on the SW by permeable cracked and creviced limestone.	The part of the reservoir below waterline which is adjacent to the limestone should be lined to prevent the water from draining down into the caves and caverns of the Kin area. The dam is to be 35 ft high and will create a reservoir with capacity to furnish a marine camp with 2,240,000 gpd. This may be enlarged to provide 5,000,000 gpd.

Table 1. Dams, dam sites, and surface-water intake points (continued)

P-4	Site for construction of the Henoko dam.	DE 042341	The stream has a drainage area of 1.8 sq miles. Flow of the stream is less than 1,000,000 gpd at high stage. Some irrigation is diverted from the stream in the upper reaches.	About 25% of the basin (47) is underlain by sandy, clayey gravel; 1% by alluvium; and the remainder by phyllite and sandstone.	A reservoir with capacity of 1,370,000 gal is planned as the source of supply for a marine camp. The capacity could be enlarged to 2,000,000 gal; with a 40 ft dam all parts of the reservoir should be watertight.
P-5	Native built intake on stream SE of Yamada where it follows subterranean channel through a limestone ridge.	CE 789233	A retaining wall one ft high has been built across stream which in August 1956 flowed at a rate of about 430,000 gpd.	The basin is very small and drainage is both surface and subsurface in this region of phyllite and cavernous limestone.	This intake has been considered as a possible source for a military installation.
P-6	Tengan-gawa intake for Tengan and Tybase Treatment Plants.	CE 852181	The Tengan-gawa is a spring-fed surface stream with flow of 6,000,000 to 8,000,000 gpd.	Surface drainage takes most of the water from this basin (61) of 12.7 sq miles. Subsurface drainage carries some of the water laterally through the limestone. The high country is underlain by Paleozoic rocks with a cover of sand, clay, and gravel; the lower country by limestone, sandy clay and gravel, and Shimajiri gray clay.	Any reservoirs developed on the Tengan-gawa would leak badly through the limestone unless all limestone surfaces were sealed.

Table 1. Dams, dam sites, and surface-water intake points (continued)

Number	Name of Location	Coordinates	Source	Geological Conditions	Comments
P-7	Intake on the Shinakawa-gawa for the Jaku Treatment Plant.	CE 792159	Stream has a flow of 2,500,000 to 2,800,000 gpd.	The basin is entirely in limestone. Much drainage is subsurface so that the stream may be drawing from a larger or smaller area than the surface drainage area.	The thickly populated watershed causes severe pollution especially during periods of rapid runoff
P-8	Intake site on the Shinakawa-gawa for the proposed Koza City Water Plant. This is upstream from the Jaku intake.	CE 804157	Stream at the Jaku intake has a flow of 2,500,000 to 2,800,000 gpd.	The basin is entirely in limestone. Much drainage is subsurface so that the stream may be drawing from a larger or smaller area than the surface drainage area.	Koza city has completed plans for a municipal water plant which will take approximately 1,500,000 gpd of water from the Shinakawa-gawa. Construction was to start about 1 July 1957 at a site approximately 2,000 ft N of the intersection of Highways 16 and 13. A part of the water used by Koza will return to the Shinakawa-gawa as sewage upstream from Jaku.
P-9	Intake at the Bishi-gawa Pump Station.	CE 770165	Flow of the Bishi-gawa at this location for the past 5 yr. has been 8,000,000 to more than 12,000,000 gpd.	Most of the basin upstream from the intake point consists of limestone terraces in which drainage is subsurface. Beach and alluvial deposits, Shimajiri sand, and Paleozoic phyllite occur only locally.	A very low dam facilitates intake. There is no impoundment. The water is pumped and piped to Tybase Treatment Plant.
P-10	Possible dam site for impoundment on	CE 771178	The Nagata-gawa is deeply incised in a	The impermeable Paleozoic phyllite capped by sand,	Stream-gage and rainfall data over a period of not less than five yr. to-

Table 1. Dams, dam sites, and surface-water intake points (continued)

	the Nagata-gawa.		valley suitable for reservoir construction. This appears to be the most suitable site in the Bishi-gawa basin for a large reservoir in impermeable rock.	clay, gravel, and some limestone would hold water in a reservoir.	gether with studies on the rate and amount of silting would be required to determine the size of reservoir to be constructed. Careful mapping of the contact between permeable and impermeable rocks should be done prior to location of the reservoir.
P-11	Possible dam site for impoundment on the Bishi-gawa.	CE 765164	This site would require shorter pipelines, but its potentialities as a suitable reservoir site are more obscure than those for P-10.	An area of impermeable phyllite is surrounded by limestone which will not retain reservoir water. A reservoir of sufficient size might be fitted into the area of phyllite.	Stream-gage and rainfall data over a period of not less than five yr. together with studies on the rate and amount of silting would be required to determine the size of reservoir to be constructed. Careful mapping of the contact between permeable and impermeable rocks should be done prior to location of the reservoir.
P-12	Intake for the Yaka Treatment Plant.	CE 861266	Mountain stream with minimum flow of about 60,000 gpd.	Stream flows through a schist formation.	The intake is at a small dam. A mile of 6-in. raw-water line carries water by gravity to the treatment plant. Water is used to supply the Enlisted Men's Recreation Center.
P-13	Intakes for Kue Treatment Plant Intake A Intake B	 CE 764116 CE 767112	Each intake is on a small spring-fed stream. Each has flows varying from 250,000 to 1,200,000 gpd.	The streams flow through cavernous limestone which overlies Shimajiri clay.	A small pond was constructed for Intake B.

Table 1. Dams, dam sites, and surface-water intake points (continued)

Number	Name of Location	Coordinates	Source	Geological Conditions	Comments
P-14	Intake on the Chantan-gawa at Sukiran motor pool raw-water station.	CE 776099	Flow is estimated at 700,000 gpd at high stage. Water is grossly polluted.	The drainage basin is 3.3 sq miles (63) and is drained by two forking streams. The area is limestone (30%) with subsurface drainage, but most water gets into the main stream. Shimajiri silt and clay underlies 70%.	The water is used only for washing vehicles.
P-15	Intake at Futema Treatment Plant.	CE 775084	Flow of spring-fed stream is estimated at 700,000 gpd. Water is grossly polluted.	The drainage basin (64) is 2.6 sq miles. Springs occur along the base of limestone at the edges of the basin which is cut almost entirely in Shimajiri clay.	The Futema Treatment Plant has been abandoned due to the excessive pollution in this densely populated area.
P-16	Intake on stream at Aza.	CE 703019	Flow near the mouth is estimated at 1,450,000 gpd at high stage. Flow diminishes greatly in the dry season. Heavy seas and typhoons contaminate fresh water with salt water.	The basin is 4.0 sq miles (69) and is cut almost entirely in Shimajiri silt and clay. Although the stream system is fed largely by surface runoff, it is also fed by springs and seeps issuing from areas of limestone and silt.	No longer used as a military water source.
P-17	Intake on stream NW of Yonabaru	CE 755009	Small dam and reservoir on a	The stream gets its water mostly from seepage from	No longer used as a military water point.

Table 1. Dams, dam sites, and surface-water intake points (continued)

	formerly used as a military water point.		little stream with flow at 15,000 to 30,000 gpd in high stage. Diminishes greatly in the dry season.	fine sand beds in the Shimajiri formation.	

are components of the system (table 2; pl. 1, Ground-water map). These are Tybase, Tengan, Jaku, Yuza, Kue, Napunja No. 1, Napunja No. 2, and Yontan. An additional one, the Futema Treatment Plant, has recently been abandoned.

Military installations on Okinawa originally were supplied from a large number of points, each using light, portable equipment to treat water for a limited number of troops. As the number of troops on Okinawa decreased some of these water points were abandoned.

With the conversion of the island to a semi-permanent garrison, after World War II, larger water-treatment plants were built and long pipelines were laid to distribute water to units far from the source. Three principal systems were constructed: Yuza to Naha Airfield, Chinen to Naha, and Tengan-RYCOM. The first two systems brought water from distant sources to the Naha area; the third was a complex delivery system which served many scattered units. No permanent water-treatment equipment was installed, however, and all water points continued to use the portable equipment on hand.

In 1949 a master plan was recommended for the development of a unified water purification and distribution system for the entire island. The Integrated Island Water System shown on the Ground-Water and Surface-Water Maps and described in Table 2 stems from this recommendation. The original Yuza to Naha Airfield and the Tengan-RYCOM systems were enlarged and united, and the Chinen to Naha system was restricted to serve only the Chinen area. The master plan (the "General Nold Report", 23 November 1949) contemplated the closing out of all temporary and semi-permanent facilities upon completion of a unified water system. However, the only permanent (constructed of reinforced concrete) type of military water plant existing is Tybase located at Katena (Kadena).

Tybase Treatment Plant has a design capacity of 8,600,000 gpd. This plant has most features of a modern purification plant, i.e., class "A" laboratory, filters with filtros plate underdrains, anthracite filter media, and hydraulic control valves. Processing includes rapid flocculation, sedimentation, rapid sand filtration, and pre- and post-chlorination. Mechanical feeders are used for dosing alum, sodium carbonate, polyphosphates, and carbon, and to enable fluoridation. There are two raw-water sources for this plant. One, the Tengan-gawa (P-6), is at a distance of seven miles and the other, the Bishi-gawa (P-9), is three miles away.

Tengan Treatment Plant is the second largest purification plant component of the Integrated Island Water System. The design capacity is 4,000,000 gpd which is in accord with the master plan, but an additional part of the plan, the 400,000 gpd pressure filter plant, was not built. Treatment facilities of the Tengan Treatment Plant are comprised of a number of bolted steel tanks which were erected by the U. S. Navy Seabees early in 1946. There are three rapid sand filters with pipe underdrains, gravel beds, and anthracite filter media, contained by 42,000-gallon tanks (8 ft high by 30 ft diameter). A bolted steel tank of 420,000-gallon capacity, with wooden baffles comprises the sedimentation facility. The clear-water basin (an equalizing and storage reservoir) consists of another 420,000-gallon steel tank. A class "B" laboratory is housed in a partial quonset at the site. Raw-water source is the Tengan-gawa (P-6).

Developed spring used by small village near Sukiran housing area. March 1957.

Sweep well at Awa, south side of Motobu-hantō, used for irrigation.

Jaku Treatment Plant is very similar in design and construction to Tengan Treatment Plant. Raw water is supplied from the adjacent stream (P-7). The Jaku plant, which has a design capacity of 1,500,000 gpd and overload capacity of 2,000,000 gpd, is placed on standby status during the low demand winter months. Plans are to phase out this installation at such time as permanent facilities are expanded to meet consumer demands.

Kue Treatment Plant is a pressure filter plant of 800,000-gpd treatment capacity. The filters and high-lift pumps are electrically driven. Raw water from two small source streams (P-13 A and P-13 B), flows by gravity to the plant where it is given the same type of treatment as is given at the Tengan Treatment Plant.

Yuza Treatment Plant has a design capacity of 700,000 gpd and is the largest facility that has a ground-water source (S-3). The spring is good quality and pre-chlorination is the full extent of treatment. Treated water flows partly by gravity and partly with the aid of high-lift pumps which are driven by diesel power to Naha Airbase, the point of its interconnection with the Integrated Island Water System.

The Napunja Treatment Plants provide for pre-chlorination only. Pumps are driven by an electric motor, model GM Peerless, 200 gpm at 200-ft. head. The two wells, Napunja well No. 1 (W-1), 91 feet deep and Napunja well No. 2 (W-2), 87 feet deep are separated approximately one-quarter of a mile. Each plant has a design capacity of 200,000 gpd. These plants, which are located at the temporary site of a marine camp, are tied to the Integrated Island Water System via the camp distribution system.

The Yontan Treatment Plant is similar to those of Napunja in regard to type of pump and treatment given. However, pumping of source well (W-5) in excess of 75,000 gpd induces salt-water intrusion. This plant is also connected to the Integrated Island Water System.

The Futema Treatment Plant which was part of the Integrated Island Water System obtained raw water from a stream which became so polluted that since 1956 water treatment has been impractical. The Futema plant has been abandoned.

Other military water systems: Water plants independent of the Integrated Island Water System include: Chinen, Ishikawa, Yaka, Easley, and Okuma (table 2; pls. 1 and 2).

The Chinen Treatment Plant has a design capacity of 430,000 gpd. The plant utilizes a large spring (S-2) which is subject to great fluctuation during and after heavy rains. The spring is good quality and pre-chlorination is the full extent of treatment. Originally the Chinen Water System was connected to the port of Naha by a gravity pipeline, but since the development of the Integrated Island Water System, the connection has been discontinued and the Chinen Water System functions as an independent unit. It provides adequately the water requirements of installations which are presently under the supervision of the U. S. Department of State.

The Ishikawa Treatment Plant has a design capacity of 10,000 gpd. It furnishes potable water to the Enlisted Men and Officers Beach Facilities. Treatment at this plant consists of pre-chlorination and

Table 2. Water treatment plants

Several abbreviations and symbols used here are: gpd - gallons per day; n.a. - not applicable; and (-) - not known. Clear-well capacity may be defined as, the capacity of a clear-water basin or equalizing and storage reservoir in a water treatment plant.

Kind	Name	Design Capacity (in gpd)	Overload Capacity (in gpd)	Clear-Well Capacity (in gpd)	Raw Water		Comments
					source of supply	amount available (in gpd)	
MILITARY WATER TREATMENT PLANTS OF THE INTEGRATED ISLAND WATER SYSTEM	Tybase	8,600,000	10,500,000	2,000,000	Bishi-gawa	8,000,000 to 12,000,000	Seasonal fluctuation of Bishi-gawa 4,000,000 gpd. Seasonal fluctuation of Tengan-gawa 2,500,000 gpd. Tengan source is combination of surface and spring water. Pollution is an increasing problem of Bishi-gawa source due to increase of native population on watershed.
					Tengan-gawa	6,000,000 to 8,500,000	
	Tengan	4,000,000	n.a.	420,000	Tengan-gawa	6,000,000 to 8,500,000	The spring-fed Tengan-gawa is a source for both the Tengan and Tybase Treatment Plants.
	Jaku	1,500,000	2,000,000	n.a.	Tributary stream of Bishi-gawa	2,500,000 to 2,800,000	Seasonal fluctuation of 300,000 gpd. Pollution is an increasing problem due to lack of watershed sewage control.
	Yuza	700,000	n.a.	80,000	Spring	500,000 to 1,500,000	Seasonal fluctuation of 1,000,000 gpd.
	Kue	800,000	n.a.	n.a.	Two small spring-fed streams	250,000 to 1,200,000	Seasonal fluctuation of 950,000 gpd.

Table 2. Water treatment plants (continued)

	Napunja No. 1	200,000	n.a.	n.a.	Deep well	>200,000	No seasonal variation. Very hard water. Not bacterially polluted.
	Napunja No. 2	200,000	n.a.	n.a.	Deep well	>200,000	No seasonal variation. Very hard water Not bacterially polluted.
	Yontan	200,000	n.a.	40,000	Deep well	75,000	Pumping in excess of 75,000 gpd cause rapid increase in chloride content.
	Futema	300,000	n.a.	n.a.	Stream	700,000	Abandoned because of gross pollution. Plant out of operation since 1956.
OTHER MILITARY WATER TREATMENT PLANTS	Chinen	430,000	n.a.	40,000	Spring	500,000	Subject to great fluctuation. Yield as much as 2,000,000 gpd after heavy rains, but decreases to 500,000 gpd in two or three days.
	Ishikawa	10,000	n.a.	n.a.	Shallow well	20,000	Subject to salt-water contamination during typhoons.
	Yaka	50,000	n.a.	n.a.	Mountain stream	60,000	Approximate dry-season yield is 60,000 gpd.
	Easley	100,000	n.a.	n.a.	Reservoir supplied by two streams		Reservoir capacity 93,000 cu ft. Constructed about 1917 by the Japanese for sugar irrigation.
	Okuma	140,000	n.a.	15,000	Stream	>5,000,000	Little seasonal variation.
OKINAWAN WATER TREATMENT PLANT	Naha City	2,600,000	3,100,000	1,000,000	Five springs	900,000 to 3,500,000	Extreme fluctuation during and immediately after heavy rains. Supplementary supplies obtained from military water system.

filtration. A shallow well (W-17) is the source of raw water.

The Yaka Treatment Plant has a design capacity of 50,000 gpd. Raw water is obtained from a mountain stream (P-12) approximately one mile away and is flowed through a six-inch steel pipe to the treatment plant. Treatment equipment consists of: three navy cubes (6 ft on a side, steel, all-purpose construction unit) for coagulation and sedimentation; one 150 gpm electrically driven pump for filter and high-lift; post-chlorinator; and a 20,000-gallon bolted, steel surge tank. The treated water is delivered to the Yaka Beach Rest Center which is a recreational facility for enlisted men.

Easley Treatment Plant is a pressure filter plant that has a treatment capacity of 100,000 gpd. Raw water flows by gravity from an impoundment reservoir (P-2) to the treatment plant approximately two miles away. Two navy cubes and one 9,000-gallon steel tank are utilized for mixing and sedimentation purposes. Processing includes coagulation, sedimentation, filtration, and pre- and post-chlorination. The raw water at this plant is unusual for Okinawan treatment plants in that it is very soft, highly corrosive, and colored by considerable organic material. Treatment is difficult and must be precise and competent. The finished water flows by gravity to the Easley Marine Camp Detachment and also to the Ryukyus Tuberculosis Sanitarium and Insane Asylum.

Okuma Treatment Plant has a design capacity of 140,000 gpd. Raw water from a stream (P-1) flows by gravity approximately one-half mile to the plant where it is given treatment to control corrosion, and is subjected to pressure filtration and pre- and post-chlorination. Treated water is delivered to both the Officers Rest Center and to the Voice of America (U. S. Information Agency) installations.

Water Supply Survey (1957)

The most recent study of the suitability of Okinawa for the development of water resources was made during January, February, and March 1957 at the request of USARYIS to the Office of the Engineer, AFFE/8A (Rear). The study was made for use in planning means of increasing the production of the Integrated Island Water System, in planning the development of water supply for Navy, Air Force, Marine, and Army units which cannot be served by the Integrated Island Water System, and in planning ways of meeting the increasing demands of Okinawans for raw water.

The specific problem was where to find and develop sources of surface and ground water, in quantities sufficient to meet native and military needs, where the least amount of pipeline would be required to get it to treatment plants and to the consumers. The big military installations are centered south of the Bishi-gawa and Tengan-gawa where the main source of water is from wells and springs. Large sources of surface water are scarce and generally poor in quality. The location of expanding native towns and cities is today greatly influenced by the location of military installations. In the agricultural economy of southern Okinawa prior to World War II, the occurrence of springs and wells largely determined the location of habitations. Now, water must be brought to large numbers of Okinawans living in areas fringing military installations.

The total production capacity of the Integrated Island Water System which serves southern Okinawa is approximately 16,000,000 gallons per day. An additional 2,000,000 gallons per day are needed to meet increasing military requirements.

Naha city will require an increase of 2,500,000 gpd in the immediate future. Although the city's treatment plant has a capacity of approximately 3,000,000 gpd, the yield from the springs constituting the raw-water source drops as low as 900,000 gpd during dry weather. Supplementary amounts must then be obtained from the military water system. In one attempt to find possible additional raw-water sources for the Naha City Water System, city officials investigated three of the four streams in the vicinity of Naha, which have a discharge of between 1,000,000 gpd and 5,000,000 gpd. These streams, the Asha-kawa, the Kokuba-gawa, and Nōha-kawa, were rejected as suitable sources for development because of either the limited quantity, pollution, existing irrigation requirements, sea-water infiltration, or too brackish quality of the water impose construction costs that were prohibitive. The fourth stream, the Mukure-kawa was considered suitable for production of 100,000 gpd of raw water for the Naha City Water System. Use of this stream is still in the planning stage.

The city of Koza is presently planning a municipal water system to supply 1,500,000 gpd. The source of raw water for this contemplated system is a tributary to the Bishi-gawa upstream from the intakes for the Integrated Island Water System. In addition, the densely populated Machinato and Tengan areas will probably both soon demand a central water-supply system. Itoman also is expected to improve its water supply.

Surface Water

Quantity and distribution

Although the flow of all streams on Okinawa reflects rainfall, with floods being common during and after rain, the regimen of streams is typical of the kind of country rock. For example, streams in areas of phyllite and sandstone release water so slowly that they seldom go dry or diminish greatly even during protracted dry spells. Streams draining areas of Shimajiri clay, on the other hand, show the most marked variation in flow because most of the rainwater runs off immediately; only that trapped in paddy fields is retained. Streams on the Shimajiri flood rapidly and subside rapidly; many go dry between rains. Streams which drain limestone areas retain their flow through normal dry spells of a few weeks. The high porosity and permeability of the Tertiary and Pleistocene coralline and detrital limestone permit the release to springs of even greater quantities of water than are released by the denser Paleozoic limestone.

Cederstrom (1947)[1/] estimated the rates of flow of several streams in southern Okinawa at a high stage in mid-June 1945 and again in mid-July of the same year following a month without rain. The Tengan-gawa, draining an area of limestone, gravel, and phyllite, showed little variation in flow. The Bishi-gawa, measured at a place where it drains

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1/ Cederstrom, D. J., 1947, Geology and water resources of southern Okinawa: Am. Assoc. of Petroleum Geologists Bull., v. 31, no. 10, p. 1752-1783.

an area of Shimajiri clay, gravel, and phyllite, and only a little limestone, diminished from 3,000,000 gpd to only 1,000,000 gpd. The spring-fed streams along the coast between Camp Kue and Naha which drain limestone areas had a 50 percent drop, but the Kokuba-gawa, which drains an area primarily of Shimajiri silty clay, dropped from 4,000,000 gpd to less than 300,000 gpd.

Potential supplies

Surface water is generally abundant in northern Okinawa and relatively scarce in southern Okinawa. All stream flows are estimated because no stream-gaging stations exist (1957). Six of the eight streams which have flow estimated in excess of 5,000,000 gpd and most of the 28 streams which have flow between 1,000,000 to 5,000,000 gpd are wholly or in part in the northern part of the island (pl. 2). In addition to having more large streams, northern Okinawa has a greater density of perennial streams per square mile. Estimates based on map studies place the stream density of northern Okinawa at more than 3 miles of perennial stream per square mile of area.

The largest streams in southern Okinawa are the Bishi-gawa and the Tengan-gawa that have flows of over 5,000,000 gpd. Other streams are very small or, like the Kokuba-gawa, have an extremely variable rate of flow. Streams are sparsely distributed in southern Okinawa and the stream density is estimated to be on the order of 1.5 miles of perennial stream per square mile of area. This sparsity is due largely to the extensive areas of limestone where most drainage is subterranean.

The drainage basins shown on Plate 2, Surface-Water Map are described in Table 3.

Quality

Both hard and soft water are common in Okinawa. Hard water is typical of the extensive limestone and clay areas which are located predominantly south of Ishikawa. This hard water averages about 250 ppm (parts per million) hardness as $CaCO_3$ (calcium carbonate). Water from the Paleozoic schist, phyllite, sandstone, and from other metamorphic and igneous rocks that compose Okinawa north of Ishikawa is generally soft. It averages 20 to 40 ppm hardness as $CaCO_3$.

The hard water is moderately scale forming and slightly corrosive when cold but heavily scale forming and moderately corrosive when hot. The scale is composed principally of calcium carbonate, some iron rust, and an appreciable amount of silica, as is shown in the following table:

Table 4. Analyses of pipe scale
(percentage by weight)

Source	Loss on Ignition	H_2O	CaO	SiO_2	MgO	Al_2O_3	Fe_2O_3
Cold water pipe (Camp Kue) 1/	44.1	1.1	30.4	11.6	9.8	2.2	1.9
Hot water pipe (Camp Kue) 1/	41.9	1.8	42.1	7.3	3.7	2.8	2.2
Source unknown 2/	41.41	1.71	51.71	0.34	0.85	0.24	4.70

Analysts:
1/ Weihe, Frick, and Kruse.
2/ Government Chemical Industrial Research Institute, Tokyo.

Table 3. Description of drainage basins

Percentages given refer to total area of the basin as shown on Plate 2, Surface-Water Map. Major stream names are given only for those streams named on standard Army Map Service maps.

No.	Major Stream Name	Area (in sq miles)	Drainage	Topography and Geology	Land Utilization	Water Utilization
1	Uku-kawa	3.9	Surface entirely. Stream gradients are steep in the hills, gentle in the alluviated parts of the valleys.	The principal valley is deep, steep walled, and cut in an elevated terrace. The lower 1.25 miles is alluviated and flat floored; the stream is incised about 5 ft into the flat floor. Above the valley floor, relief is high. Paleozoic phyllite and sandstone underlie most of the basin. Alluvium occurs only in the valley floor.	Valley flats (5%) are in rice culture. Hillsides (15%) near Uku are terraced and planted to sweet potatoes, vegetables, and small grains. The remainder of basin (80%) is forested.	Most water is not utilized. Some is used for paddy areas and for Uku village.
2		1.6	Same as above.	The principal valley is deep, steep walled, and cut in an elevated terrace. The lower 0.1 mile is flat floored; the relief of the remainder of the area is high. The stream is incised about 5 ft in the flat floor; elsewhere it flows in a narrow V-shaped canyon. Paleozoic sandstone and phyllite underlie most of the basin and a small area of sandy, clayey gravel occurs on ridgetops near the coast. Alluvium is in the valley floor.	Rice is grown on the flat valley floor (1%). A small percentage of the hillsides have been terraced and planted to vegetables. The remainder is forested.	A little water is diverted to the paddy fields.

Table 3. Description of drainage basins (continued)

No.	Major Stream Name	Area (in sq miles)	Drainage	Topography and Geology	Land Utilization	Water Utilization
3	Uga-gawa	1.1	Surface entirely. Stream gradients are steep in the hills, gentle in the alluviated parts of the valleys.	The principal valley is deep, steep walled, and cut in an elevated terrace. The lower 0.1 mile is flat floored on alluvium into which the stream is incised about 5 ft. Elsewhere relief is high; accordant flat-topped ridges mark remnants of the elevated terrace. A few terrace remnants near the coast are capped by sandy, clayey gravel. Bedrock is Paleozoic sandstone.	Rice is grown on the valley floor (1%). Dryland crops such as vegetables, sweet potatoes, and small grains are grown on hillsides and ridgetops (8%). Remainder is forested.	Some water is diverted to the paddy fields, and a little is used in Uka.
4		2.0	Surface entirely. Stream gradients are gentle near the mouth, moderate to steep in major courses.	The principal valleys are deep, steep walled, and cut in an extensive elevated terrace; small tributary streams are incised about 100 ft into the terrace on which are a few remnants of sandy, clayey gravel near the coast. Bedrock is Paleozoic phyllite. Alluvium is in the lower 0.2 mile of the principal valley.	Rice is grown on the valley floor (1%). Almost all of the remainder of the basin is forested.	A small amount of water is diverted to paddy fields, and a little is used for domestic requirements.
5	Benoki-gawa	5.6	Surface entirely. Stream gradients are steep except in the lower reaches of the major stream.	The basin includes dissected terrace and mountains. Relief is high except for the flat alluvium-covered parts of the major stream valley. Bedrock is chiefly Paleozoic sandstone with some phyllite in the western portion.	Rice is grown in the stream valley (3%). Hillsides (5%) are terraced and planted to dry crops. The remainder is forested.	Same as above.
6	Soshu-gawa	1.1	Same as above.	The basin is a part of an extensive dissected, elevated terrace. The tributaries are incised about 100 ft into the terrace	Rice is grown in the flat valley floor (1 to 2%). Some hill-	Same as above.

Table 3. Description of drainage basins (continued)

				surface and join the principal stream with marked increase in gradient. Bedrock is Paleozoic sandstone capped by sandy, silty gravel. Alluvium is in the lower part of the major valley.	sides and ridgetops (4%) are cultivated in dryland crops. The remainder is forested.	
7	Sate-gawa	2.5	Same as above.	The basin includes areas of dissected, elevated terrace and mountains. Relief is high and streams are deeply incised. Bedrock is Paleozoic sandstone and phyllite. Alluvium is found in the lower 0.1 mile of the stream valley.	Rice is grown on valley flats (1%). Some hillsides are terraced and cultivated (3%). The remainder is forested.	Same as above.
8		1.2	Same as above.	The basin is a part of an extensive dissected, elevated terrace. Relief is high. Bedrock is Paleozoic phyllite capped by sandy, clayey gravel. Alluvium is in the flat-floored lower valley of the major stream.	Same as above.	Same as above.
9		1.4	Surface entirely. Stream gradients are steep except in the lower reaches of the major stream.	The basin is a part of an extensive dissected, elevated terrace. Relief is high. Bedrock is Paleozoic phyllite capped by sandy, clayey gravel. Alluvium is in the flat-floored lower valley of the major stream.	Rice is grown on valley flats (1%). Some hillsides are terraced and cultivated (3%). The remainder is forested.	A small amount of water is diverted to paddy fields, and a little is used for domestic requirement.
10	Yona-gawa	4.4	Same as above.	The basin includes areas of dissected, elevated terrace and mountains. Relief is high except in the alluvium-covered flat floor of the lower 0.8 mile of the major valley. Bedrock is Paleozoic sandstone and phyllite.	Rice is grown on the alluvial flats (4%). Terrace remnants and some hillsides (8%) are farmed to dry crops. The remainder is forested.	Water is diverted for paddy fields and local use.

Table 3. Description of drainage basins (continued)

No.	Major Stream Name	Area (in sq miles)	Drainage	Topography and Geology	Land Utilization	Water Utilization
11	Ura-kawa	1.8	Surface entirely. Stream gradients are steep except in the lower reaches of the major stream.	The basin includes areas of dissected, elevated terrace and mountains. Relief is high except in the alluvium-covered flat floor of the lower valley. Bedrock is Paleozoic greenstone and phyllite.	Rice is grown on the valley floor (2%). Some hillsides and ridgetops (2%) are cultivated. The remainder is forested.	Some water is diverted for paddy fields and local use.
12	Fūkū-gawa	6.6	Surface entirely. Stream gradients are steep except in the lower part of the major course where they are gentle to moderate.	The basin includes areas of dissected, elevated terrace and mountains. Relief is high except in the alluvium-covered flats of the river mouth. Bedrock is Paleozoic sandstone and phyllite. A little sandy, clayey gravel caps terrace remnants.	Except for a few paddy fields the basin is forested.	A little water is diverted to flood the paddy fields.
13	Ada-gawa	3.4	Surface entirely. The major stream forks into three streams near its mouth. Except in the alluviated part of the valleys, all gradients are steep.	The basin includes areas of the dissected, elevated terrace; the western part is mountainous. Bedrock is Paleozoic phyllite and sandstone. Sandy, clayey gravel caps the terraces. Less than 2% of the basin is alluvium.	Paddy fields and villages occupy 6% of the area. Some hillsides and ridgetops (12%) are cultivated to dry crops. The remainder is forested.	A moderate amount of water is diverted for paddy fields and local use, but most is unused.
14	Hiji-gawa	6.1	Surface throughout most of the basin. Some subsurface in the limestone near the stream mouth.	The western part of the basin is a dissected elevated terrace; the eastern part is mountainous. Bedrock is Paleozoic phyllite, sandstone, greenstone, and limestone. Less than 2% of the basin is underlain by alluvium.	The alluviated valley bottom is used for rice culture. Hillsides and ridgetops (6%) are under dry cultivation. The remainder is forested.	The principal stream is dammed, and much of its water diverted for native use, irrigation, and the Okuma Treatment Plant.

Table 3. Description of drainage basins (continued)

15	Aha-kawa	10.1	Surface entirely. River forks about two miles above the mouth. Gradients are gentle to moderate on the principal streams and steep on tributaries.	Most of the basin is a dissected, elevated terrace, but the western part includes mountains. The terrace remnants here are the highest on Okinawa. Relief is low in the alluvium-covered part of the major stream valley. Bedrock is Paleozoic phyllite and sandstone capped by scattered remnants of sandy, clayey gravel.	The valley bottom (1%) is used for rice culture. Some of the hillsides and terrace tops (5%) are farmed to dry crops. The remainder is forested.	A minor amount of water is diverted to flood paddy fields.
16		3.7	Surface throughout most of the basin. Some is subsurface toward the sea through limestone near the coast. Gradients are steep except on alluviated valley floors.	The western part of the basin is dissected, elevated terrace; the eastern part is mountainous. Extensive alluvial flats occur along the lower portion of the principal valley. Bedrock is Paleozoic phyllite, sandstone, greenstone, and limestone.	The alluvial flats (4%) are under rice cultivation. Some hillsides and ridgetops (10%) are under dry cultivation. The remainder is forested.	Water is diverted to flood paddy fields and for domestic use.
17	Kijoka-gawa	1.8	Surface entirely. Stream gradients are steep except on the alluviated valley floors.	The basin lies mostly in a dissected, elevated terrace, but the eastern portion is in the backbone ridge of mountains. Alluvial flats comprise 7 to 8% of the basin area. Bedrock is Paleozoic phyllite, sandstone, and greenstone.	Most of the alluvial flats are covered by paddy fields. Dry crops are cultivated on hillsides and ridgetops (20%). The remainder is forested.	Much of the water is used for irrigation or to meet domestic requirements.

Table 3. Description of drainage basins (continued)

No.	Major Stream Name	Area (in sq miles)	Drainage	Topography and Geology	Land Utilization	Water Utilization
18	Nyūha-gawa	1.6	Surface except in limestone areas where most or all of the water sinks into the limestone and eventually drains into the major stream. Gradients are steep except for the lower 1.5 miles.	The western half of the basin is dissected terrace, and the eastern half is limestone mountains. Relief is high everywhere except on the narrow alluvium-covered valley floor. Terrace remnants are capped by a layer of sandy, clayey gravel. Bedrock is Paleozoic phyllite, greenstone, and limestone.	About three-quarters of the valley flats (3%) is flooded for rice culture. The remaining quarter is populated. Terraced hillsides (8%) are under dry cultivation. The remainder is forested.	Some water is used for irrigation and village needs.
19	Ara-kawa	4.3	Surface entirely. A single, deeply incised stream with a steep gradient.	Most of the basin is cut in the extensive broad terrace on the east side of the island. The mountainous backbone flanks the western edge. The basin is underlain mainly by Paleozoic sandstone and phyllite. Sandy, clayey gravel occurs on a few terrace remnants. No alluvium is present.	The basin is almost completely forested.	No water is used.
20		2.4	Same as above.	The basin is part of the extensive elevated terrace on the east side of the island. Slopes are steep, rising to flat-topped ridges at a concordant altitude. A few patches of sandy, clayey gravel are on some of the terrace remnants near the coast. Bedrock is Paleozoic phyllite and sandstone.	Most of the basin is forested.	Same as above.

Table 3. Description of drainage basins (continued)

21	Ō-kawa	7.5	Surface except on limestone (15 to 20% of the basin). Some of the water which falls on the limestone feeds springs above Tammya, outside the basin, but most reenters the surface system of this basin.	The basin includes areas of dissected, elevated terrace and mountains. Several broad arable upland valleys are in the region of the steep limestone mountains. Relief is generally high except in the upland valleys and the alluvial flats in the lower portion of the valley. Bedrock is Paleozoic phyllite, limestone, and greenstone.	One percent is paddy fields; about 10% is planted to dryland crops; and the remainder is forested.	Some water is diverted for irrigation, but most is not utilized.
22	Fukuchi-gawa	12.2	Surface entirely. The drainage pattern follows faultlines. Gradients are gentle in the lower reaches of streams and moderate elsewhere. Steep gradients are local between moderately sloping stretches.	The western edge of the basin is flanked by the backbone ridge of mountains, but most of the basin is a dissected, elevated terrace with steep-sided, flat-topped ridges. The general level of the terrace is broken by north-facing fault scarps, which are reflected in straight east-west stream valleys. About 98% of the basin is underlain by Paleozoic sandstone and phyllite.	The paddy fields are on the alluvial flats (1%). Hillsides and ridgetops (3%) are planted to dry crops. The remainder is forested.	A little water is diverted to flood paddy fields.
23		2.1	Surface entirely. The drainage pattern largely follows faultlines. Stream gradients are low to moderate for all large streams, steep in small tributaries.	The basin is entirely in the extensive dissected, elevated terrace on the east coast of Okinawa. Flat-topped ridges separated by steep-sided canyons are typical. Most of the ridgetops are capped by sandy, clayey gravel. Bedrock is Paleozoic sandstone and phyllite.	About 3% of the basin is cultivated to rice; 6% to dryland crops; and the remainder is in forest.	Some water is diverted to flood the paddy fields.

Table 3. Description of drainage basins (continued)

No.	Major Stream Name	Area (in sq miles)	Drainage	Topography and Geology	Land Utilization	Water Utilization
24	Hinan-gawa	4.0	Surface entirely. Stream forks near the mouth. The northern fork descends by falls to the valley floor. Gradients are low in the principal valley, moderate to steep elsewhere.	The basin is dissected, elevated terrace, except the eastern edge in the W slope of the backbone range of mountains. About 98% of the basin is underlain by Paleozoic sandstone, phyllite, and greenstone. About 2% is alluvium.	Paddy fields cover about 2% of the basin; hillsides and ridgetops planted to dryland crops, about 2%; and the remainder is forested.	Water is diverted to irrigate the paddy fields.
25	Minato-gawa	2.7	Surface entirely. Low gradients prevail in an extensive area near the headwaters of the river, but stretches of steep gradients separate them from the low gradient stretches near the mouth.	Most of the basin is dissected, elevated terrace. The western edge is the E slope of the backbone range of mountains. Steep-sided canyons separate the flat-topped terrace remnants, capped by sandy, clayey gravel. Alluvium is on the valley floor. Bedrock is Paleozoic sandstone and phyllite.	About 1% is paddy fields; 1% is tidal swamp; and 1% is cultivated to dry crops. The remainder is forested.	Water is diverted to flood the paddy fields.
26	Haneji-gawa	5.4	Surface entirely. Major streams have low to moderate gradients. All smaller streams have steep gradients. From the	The basin includes areas of dissected, elevated terrace, mountains, and dissected, low gravel terrace. Narrow alluvial flats occur along the principal stream and major tributaries for several miles E of the Nago fault. Bedrock is porphyry and Paleozoic greenstone and phyllite.	Towns occupy about 1%; paddy fields a little more than 1%; fields cultivated to dry crops, about 3%; and the remainder is forested.	A dam, with reservoir silted up, is used to divert water to paddy fields.

Table 3. Description of drainage basins (continued)

			Nago fault scarp west, the river course has been modified to flow in a manmade channel.			
27	Makiya-gawa	1.6	Surface entirely. Stream gradients are moderate to steep.	The basin includes areas of an elevated terrace. Its southern edge is a scarp along the north side of a mountain. A few small patches of sandy, silty clay cap remnants of the terrace. Bedrock is porphyry, and Paleozoic greenstone and phyllite.	Cultivated fields comprise about 5% of the basin, and forests cover the remainder.	A dam near the mouth of the canyon diverts water to the town of Maajiya and to the paddy fields on the coastal flat. The reservoir is silted and now provides little storage.
28	Genka-gawa	7.9	Surface entirely. Stream gradients are low to moderate on the principal streams, steep on the tributaries.	The basin includes areas of dissected, elevated terrace and mountains. The stream breaches the backbone mountainous ridge. Extensive alluvial flats occur in the lower course of the principal stream and one of its tributaries. Bedrock is Paleozoic sandstone, phyllite, and greenstone.	About 1% is occupied by a village; 2% by paddy fields; 3% by cultivated dry crops, and the remainder is in forest.	Some water is diverted to the paddy fields.

Table 3. Description of drainage basins (continued)

No.	Major Stream Name	Area (in sq miles)	Drainage	Topography and Geology	Land Utilization	Water Utilization
29	Arume-gawa	1.6	Surface entirely. From the S, the principal tributary joins the main stream at Arume. Stream gradients are low in the alluviated parts of valley, steep elsewhere.	The basin includes areas of dissected, elevated terrace and mountains. Faulting controls the position and shape of the major streams. The lower portion of the valley along both forks of the stream are flat floored and alluvium covered. Several flat-topped ridges are capped by sandy, clayey gravel. Bedrock is Paleozoic sandstone and phyllite.	Paddy fields are on the alluvial flats (about 7%). About 10% is in dry crops, and the remainder is brush covered.	About half the water is diverted for domestic and agricultural use.
30	Atsutabaru-gawa	2.7	Surface entirely. Stream gradients are steep everywhere except in the lower alluviated part of the principal valley.	The basin is developed in a little block of the elevated terrace. Sides of remnants are high and steep, but relief on the surfaces is moderate. About 98% of the basin is underlain by Paleozoic sandstone and phyllite.	Paddy fields occupy about 1%; cultivated fields about 2%; and forest the remainder.	Water is diverted to flood the paddy fields.
31		1.8	Largely surface. The area of porous, detrital limestone near the mouth may have subsurface in addition to surface drainage, but the limestone is a small part of the total area. The	The basin consists of mountains and a series of terraces along the N side. Relief is high, especially in the W where limestone cliffs are several hundred feet high. The basin consists of Paleozoic phyllite, sandstone, and chert, Paleozoic limestone, porous detrital limestone, alluvium, and raised beach deposits.	About 6% is paddy fields; 10% is cultivated fields; and the remainder is forested.	Water is diverted for the paddy fields.

Table 3. Description of drainage basins (continued)

			large mass of Paleozoic limestone to the W probably contributes some water. Stream gradients are moderate to steep.			
32	Yonamine-gawa	1.6	About 50% of the basin is drained in part, at least, by subsurface flow. A surface drainage pattern is developed over most of the basin. Stream gradients are low to moderate in 60% of the area, steep in about 40%.	Most of the basin is on limestone terraces along the N side of Motobu-hantō; only the upper parts of the streams drain the dissected, elevated terrace and mountains. Local beach sand on the extensive high-level surface show old shorelines. The basin consists of Paleozoic phyllite, sandstone, and chert, Paleozoic limestone, porous detrital limestone, alluvium, and raised beach deposits.	Towns occupy about 14%; paddy fields 13%; cultivated fields 43%; and forests 30%.	Much of the water is utilized to meet agricultural and domestic requirements.
33	Gumma-gawa	1.3	About 45% of the basin is drained mostly by subsurface flow; the remainder by surface runoff. Stream gradients are low to moderate in the northern half of the basin; steep in the southern half.	The basin includes areas of limestone terraces of low to moderate relief, and dissected terraces and mountains of high relief. Bedrock is Paleozoic phyllite, sandstone, and chert, Paleozoic limestone, and porous detrital limestone.	Towns cover about 4% of the area; paddy fields 6%; cultivated fields about 60%; and forests the remainder.	Water is diverted to flood the paddy fields.

Table 3. Description of drainage basins (continued)

No.	Major Stream Name	Area (in sq miles)	Drainage	Topography and Geology	Land Utilization	Water Utilization
34		1.1	Largely subsurface, although small surface streams are present. Gradients are low to moderate in the northern half of the basin; steep in the southern half.	The northern half of the basin is a limestone terrace and has moderate relief; the mountainous southern half has high relief. The terraces are underlain by porous, permeable, detrital limestone which has a thick residual soil cover. The mountains are hard crystalline Paleozoic limestone.	Towns cover about 10%; paddy fields 7%; cultivated fields 65%; and forests the remainder.	Water is diverted to flood the paddy fields.
35	Unten-gawa	1.2	Primarily subsurface.	Most of the basin lies on a limestone terrace. Relief is moderate over most of the basin and low in the paddy fields.	About 14% is paddy fields; 13% village; and the remainder cultivated fields interspersed with homes and forest.	Most of the water is diverted for agriculture.
36	Manna-kawa	4.6	Largely surface. Stream gradients are low in the alluviated valley of the principal stream; steep elsewhere.	Terraces and mountains are included in the basin. Relief is high except in the alluvium-covered valley floor and terrace remnants where it is low to moderate. About 3% of the basin is porous, detrital limestone; 5% is alluvium; 5% is sandy, clayey gravel; 30% is Paleozoic limestone, and the remainder is Paleozoic phyllite, sandstone, chert, and greenstone.	About 3% is villages; 5% is paddy fields; 30% is cultivated fields; and the remainder forest or brush covered.	A dam on the Manna-kawa diverts water for agricultural use. During World War II the armed forces had a water point above the dam to supply water to Motobu Airfield.

Table 3. Description of drainage basins (continued)

37	Ōi-kawa	6.2	Drainage is both surface and subsurface. Stream gradients are moderate to steep except in alluviated areas where they are low to moderate. Few streams are permanent in the Paleozoic limestone areas.	The basin is cut along the fault trace which divides the Motobu-hantō. Relief is generally high and the slopes are steep especially in areas of Paleozoic limestone. The basin is underlain by alluvium near the mouth; 4% of the basin is sandy, clayey gravel; 1% is porous, detrital limestone; 33% is Paleozoic limestone and the remaining 62% is Paleozoic phyllite, sandstone, clay slate, and chert.	About 2% is paddy fields; 1% villages; 17% cultivated fields; and the remainder is forest.	Water is diverted to flood paddy fields, and some is used for domestic purposes.
38	Ufugumi-gawa	1.8	Drainage is surface except locally in limestone areas. Stream gradients are moderate in major streams; steep in tributaries.	The basin is cut mostly into elevated terrace areas and mountains. Relief is low to moderate on terrace remnants which are separated by steep-walled canyons from 30 to 150 ft deep. About 1% is alluvium; 15% is sandy, clayey gravel; 30% is Paleozoic limestone, and 54% is Paleozoic phyllite, chert, and sandstone.	Rice is grown on about 1% of the basin. The remainder is dryland crops, brush, grass, and forest.	Some water is diverted to flood paddy fields.
39	West fork of Yabu-gawa	3.0	Drainage is surface over most of the basin. Subsurface drainage occurs in limestone areas. Stream gradients are low to moderate.	The basin includes areas of dissected, elevated terrace and mountains. Relief in the northern part is moderate to high. The basin is alluvium along the major streams (4%); sandy, clayey gravel (10%); Paleozoic limestone (15%); and Paleozoic phyllite and sandstone (71%).	About 4% is paddy fields; 8% is cultivated crops; and the remainder is forest and brush.	Much of the water is diverted to flood paddy fields. A dam at the mouth diverts about half of the water into a system of irrigation canals.

Table 3. Description of drainage basins (continued)

No.	Major Stream Name	Area (in sq miles)	Drainage	Topography and Geology	Land Utilization	Water Utilization
40	Haneji-o-kawa	5.6	Surface entirely. The stream has two forks, the eastern of which is the larger. Stream gradients are low in the central part of the basin, steep in the mountains along the E and W sides.	The central third of the basin lies on the low neck of Motobu-hantō. Relief is low to moderate on soft sandy, clayey gravel-covered surfaces. The western third lies on the dissected, elevated terrace of the peninsula. Relief is high on this portion underlain by Paleozoic sandstone, phyllite, and chert. The eastern third includes the dissected, elevated terrace underlain by Paleozoic greenstone and phyllite. Relief is high.	Paddy fields comprise about 15%; towns 3%; cultivated fields 20%; and forest the remainder.	Most of the tributaries are diverted to flood paddy fields. A small, earth-fill dam has been constructed on the W side of the basin to furnish water for irrigation during the dry season.
41	East fork of Yabu-gawa	4.6	Surface entirely. A dam across the mouth of the principal stream prevents the lower reaches from being tidal.	The central half of the basin is cut in soft sand and gravel which form the low neck of the Motobu-hantō. Broad alluvial flats flank the streams and are bordered by steep-sided gravel hills. The W side of the basin consists of a high elevated terrace underlain by Paleozoic rocks capped by sandy gravel. The eastern tip extends into the mountains on the mainland of Okinawa.	Paddy fields comprise about 19% of the area; cultivated fields 20%; forest and brush the remainder.	Much water is diverted to irrigate paddy fields.
42	Yofuke-gawa	1.5	Surface entirely. Stream gradients are low in the alluviated lower	The basin is cut into the backbone ridge of mountains and the elevated terrace on the W side of the island. The basin is underlain by phyllite and dike rock (98%),	The paddy fields are on alluvial flats (2%). Terraced cultivated fields occupy	The main stream is a source of water for domestic purposes.

Table 3. Description of drainage basins (continued)

			part of valley; steep elsewhere.	and alluvium (2%).	3% of the basin. The remainder is forest.	A little water is diverted from tributary streams to irrigate paddy fields.
43	Ōra-kawa	3.6	Surface entirely. Stream gradients are low in the principal stream but steep in the tributaries.	The basin is cut on the flank of the backbone range and the eastern elevated terrace. Steep-sided, flat-topped ridges of sandstone and phyllite are capped in places by sandy, clayey gravel. Alluvium covers the flat valley floors in about 3% of the basin.	Rice is grown on the alluvial flats, and dry crops on higher land. The remaining 94% of the basin is forested.	Water is diverted to flood the paddy fields.
44	Fukuchi-gawa	4.7	Surface entirely. Lower reaches of streams are tidal. Stream gradients are low in the alluviated parts of the valleys; steep elsewhere.	The basin is cut into the elevated terraces and the E flank of the backbone ridge of mountains. Except for alluvial and tidal flats, relief is high. Sandstone underlies 97% of the basin and alluvium about 3%.	Paddy fields occupy 3%; cultivated fields 3%; and the remainder is mostly brush.	Same as above.
45	Teniya-gawa	1.8	Surface entirely. Gradient of the principal stream is low to moderate; gradients of tributaries are steep.	The basin is cut on tilted segments of the eastern elevated terrace. Relief on the N side is low to moderate; on the S side it is high. The basin is formed of alluvium (3%), sandy, clayey gravel (35%), and sandstone (62%).	Rice grows on the alluvial flats (3%); dry crops are on higher land (8%); and the remainder is forest.	Same as above.

Table 3. Description of drainage basins (continued)

No.	Major Stream Name	Area (in sq miles)	Drainage	Topography and Geology	Land Utilization	Water Utilization
46	Sukuda-gawa	1.4	Surface entirely. Stream gradients are low in the alluviated lower parts of the valley; moderate in the upper reaches of the main stream; steep in the tributaries. Between the upper and lower reaches of the main stream is a falls about 100 ft high.	The basin has generally high relief except where alluvial flats border the lower stretches of the stream below the falls, and relief is low. About 97% of the basin is underlain by phyllite and 3% by alluvium.	About 2% is paddy fields; 2% terraced cultivated hillsides; and the remainder is forest.	Water is conducted by a canal from the base of the falls to paddy fields.
47	Fukuchi-gawa	1.8	Surface drainage entirely. The stream course is fault controlled throughout the upper reaches where it is essentially straight. Gradients low to moderate to major stream and steep in tributaries.	The basin includes elevated, dissected terrace remnants and mountains. Flat-topped spurs and ridges are capped by sandy, clayey gravel along both sides of the basin in its lower parts. The ridges are generally without gravel capping near the mountain front. Bedrock is phyllite and sandstone.	Rice is planted on narrow patches of alluvium in the valley bottom. During World War II, in the part of the basin used as a refugee camp, ridgetops were cleared, accelerating erosion.	Some irrigation water is diverted from the upper reaches of the stream.
48	Henoko-gawa	1.2	Surface entirely. Stream gradients	Most of this basin is cut in the broad eastern terrace and the steep E face of	Paddy fields comprise 3 to 4% of the floor	Water is diverted to flood

Table 3. Description of drainage basins (continued)

			are low in the alluviated valley; moderate to steep elsewhere.	the backbone range of mountains. Slopes are steep except for relatively flat ridgetops capped by sandy, clayey gravel. Bedrock is sandstone and phyllite.	of the lower valley. Extensive areas are being prepared (1957) for construction of a large military camp.	paddy fields. A reservoir with a dam 40 ft high is planned to supply the camp.
49	Nato-kawa	2.5	Same as above.	The basin is cut in the elevated, dissected terrace and the E face of the backbone range of mountains. The streams are in narrow steep-walled valleys separated by round-topped, gravel-capped ridges. The lower valley is cut in thick deposits of sandy, clayey gravel. Bedrock is sandstone and phyllite.	Rice occupies about 5% of the basin; cultivated fields about 4%; and forest the remainder.	Water is diverted to flood paddy fields.
50	Kise-gawa	2.0	Same as above.	The basin is cut in the backbone range of mountains and the western terrace. Slopes are steep and ridgetops are narrow. About 8% is underlain by alluvium; 1 to 2% by sandy, clayey gravel; about 8% by rhyolite-porphyry, and the remainder by sandstone and phyllite.	Villages occupy about 2% of the basin; paddy fields 6%; cultivated fields about 3%; and forest 89%.	Water is diverted to flood paddy fields and some is used for domestic purposes.
51	Nakama-gawa	1.1	Same as above.	The basin is cut in the western elevated terrace. Ridges in the northern part are flat topped and gravel capped. In the southern and eastern parts they are narrow and covered with residual soil. Slopes are steep except on the alluviated valley floor. Alluvial and beach deposits form about 7% of the basin; clayey, sandy gravel 6%; rhyolite-porphyry 30%; and sandstone 57%.	Villages occupy 3 to 4%; paddy fields 3 to 4%; cultivated fields about 3%; and forest the remainder.	Water is diverted to flood paddy fields and is piped into town for domestic use.

Table 3. Description of drainage basins (continued)

No.	Major Stream Name	Area (in sq miles)	Drainage	Topography and Geology	Land Utilization	Water Utilization
52	Kanna-kawa	3.9	Surface entirely. Stream gradients are low to moderate in alluviated parts of valley; moderate to steep elsewhere.	The basin is cut in the eastern terrace and the eastern flank of the backbone range. Ridgetops in the southeastern part are flat and gravel capped. Alluvium underlies 3% of the basin on the valley floor; clayey sand and gravel about 20%; and sandstone the remainder.	Paddy fields occupy about 2% of the basin; cultivated fields about 8%; and forest the remainder.	Water is diverted to flood paddy fields.
53	Ginoza-gawa	2.9	Surface in 90% of basin; drainage is subsurface in about 10% which is limestone. Springs are numerous on the down-dip margin of the limestone. Stream gradients are low to moderate.	The basin is cut in the eastern elevated terrace and E flank of the backbone mountain range. The southern edge is a limestone terrace; about 2% is alluvium in long valley bottoms; 10% is limestone; 15% is sandy, clayey gravel; and the remainder is sandstone.	Town and houses occupy about 2% of the basin; paddy fields 3 to 4%; and cultivated fields and forests the remainder.	Water is pumped from a point on the stream at the edge of Jinoza. This is supplemented by water brought by a gravity pipeline.
54	Onna-gawa	1.5	Surface in all but a small area of limestone. Two streams join near beach. Gradients are low near the coast; moderate to steep elsewhere.	The basin is cut in the backbone range of mountains and the western elevated terrace. About 7% of the basin is alluvium; 2% is porous, detrital limestone; 10% is sandy, clayey gravel; and the remainder is phyllite.	Paddy fields make up 7% of the basin; cultivated fields and forest the remainder.	Water is diverted to flood paddy fields.
55	Afuso-gawa	2.0	Surface entirely.	The basin is cut in the backbone range of	The town occupies 1 to	Water is di-

Table 3. Description of drainage basins (continued)

			Stream gradients are low in the alluviated parts of the valley; steep elsewhere.	mountains and the western elevated terrace. The northern half of the basin consists of flat-topped, gravel-capped ridges, separated by narrow steep-sided valleys; the southern half is steeply sloping narrow mountain ridges. About 6% of the basin is alluvial and beach deposits; 10% is sandy, clayey gravel; and the remainder is sandstone and phyllite.	2%; paddy fields 4 to 5%; and cultivated fields and forest the remainder.	verted to flood paddy fields.
56	Nanri-gawa	5.2	Surface in about 94% of basin; subsurface in about 6%. Ground water probably enters basin from limestone area under Chimmu Airfield. Principal streams have low to moderate gradients; tributary streams moderate to steep.	The basin includes a large gravel-filled embayment in the backbone ridge of the mountains in which relief is low to moderate, mountains, high dissected terrace areas, low limestone terrace areas, and alluvial flat. The porous, detrital limestone and sandstone are capped by sandy, clayey gravel.	About one-quarter of the basin is in paddy fields and cultivated fields; forest and towns occupy the remainder.	Water is diverted to flood paddy fields. A dam, about 35 ft high, and reservoir are planned to supply water to a large military camp to be established here (1957).
57	Ishikawa-gawa	4.2	Surface in 85% of basin; subsurface in 15%. Principal stream is fed by several small streams that join in the flats behind the town of Ishikawa. Stream gradients are low to moderate.	Most of the basin is cut in elevated terrace areas and the backbone ridge of mountains. Local relief over most of the basin is low to moderate. Alluvium and beach deposits form about 20% of the basin; porous detrital limestone 15%; sandy, clayey gravel 30%; and phyllite 35%.	About one-quarter of the basin is in paddy fields and cultivated fields; forest and towns occupy the remainder.	Water is diverted to flood paddy fields.

Table 3. Description of drainage basins (continued)

No.	Major Stream Name	Area (in sq miles)	Drainage	Topography and Geology	Land Utilization	Water Utilization
58	Maeta-gawa	1.5	A single stream drains most of basin; coastal limestone areas drain to the sea by subsurface drainage. Stream gradients are steep upstream from the flat-floored alluviated valley.	Paleozoic rocks and sandy clay and gravel underlie about 85% of the basin. Limestone composes 15% of the basin. Steep-sided ridges rising to a common elevation have high to moderate relief.	About 20% of the basin is cultivated. The remainder has a natural brush cover.	Water is used locally by natives.
59	Nagahama-gawa	2.2	This basin is drained by one surface stream. The upper plateau has subsurface drainage, but most of it is tributary to the stream. Stream gradients are steep in the hills and low in the flat-floored valley of the lower course.	The basin is cut in a series of terraces composed of Paleozoic rocks and limestone covered with sandy clay and gravel. One hill of Paleozoic rock rises above the upper terrace level.	About one-fifth of the basin is cultivated. The remainder is in natural scrub and part of an airfield.	The water of this stream is not utilized.
60	Bishi-gawa	19.6	Surface drainage is well developed in areas of Paleozoic	The basin is formed by the dissection of a series of limestone terraces. Beach and alluvial deposits occur locally. The	Military installations occupy much of the basin, and in the SE	The basin supplies water to Tybase and Jaku

Table 3. Description of drainage basins (continued)

			schist and phyllite. Subsurface drainage is in limestone areas. Some ground water moves laterally through the limestone into the neighboring basins.	Nagata-gawa, a northern tributary to the Bishi-gawa, drains an area of Paleozoic phyllite.	are native villages. Cultivation is chiefly in dryland crops.	Treatment Plants.
61	Tengan-gawa	12.7	The principal stream carries most of the water from this basin. Subsurface drainage is in areas of limestone and some water seeps out of the basin laterally through the limestone.	The drainage basin is cut into a series of terraces. The lower levels, developed largely on limestone, have low relief. The upper levels are marked by flat-topped ridges and steep-sided, flat-floored valleys. Dissection increases inland where the high country is composed of Paleozoic rocks with a cover of sandy clay and gravel. The lower country is limestone, sandy clay and gravel, and Shimajiri gray clay.	Military reservations and villages are extensive. Dry crops and rice are grown where the land permits.	The Tengan-gawa supplies water to the Integrated Island Water System.
62	Noguni-gawa	3.4	The basin is drained principally by two forks of a single stream. Surface drainage is poorly developed in the airbase area. Much water probably seeps out of basin through underground circulation.	The northern half of the basin is a plain. Relief is low. The southern half has a closely spaced pattern of steep-sided, flat-topped ridges and narrow, flat-floored valleys. The entire basin is developed in limestone with some cover of residual sandy clay.	Kadena Airbase, other military reservations, and native villages occupy most of the basin.	The streams are no longer used as a military water source.

Table 3. Description of drainage basins (continued)

No.	Major Stream Name	Area (in sq miles)	Drainage	Topography and Geology	Land Utilization	Water Utilization
63	Chatan-gawa	3.3	The basin is drained by two forks of one stream. Limestone areas have subsurface drainage, but most water gets into the main stream. Lower course of stream is between high limestone walls and is subject to floods.	Limestone caps steep-sided high ridges and lines the banks of the stream in about 30% of the basin. The Shimajiri fine sand and silt stands in steep slopes in about 10% of the basin, and Shimajiri clay forms a rolling topography over about 60% of the basin.	Steep slopes and ridges have a natural cover of scrub and grass. Rolling land largely under military use and native habitations.	The Chatan-gawa furnishes water to water point P-14 used by the Sukiran motor pool.
64	Futema-gawa	2.6	The basin is drained by the Futema-gawa, a single long stream. Small springs, tributary to this stream, occur along the base of the limestone at the edge of the basin.	The basin is cut almost entirely in Shimajiri clay, although minor amounts of limestone flank the basin in the N. The valley of the Futema-gawa is wide and has moderate relief where it is cut in clay; it is narrow and steep walled where it crosses limestone.	This area is largely under habitation and cultivation with the exception of steep slopes.	Water point P-15 is at the mouth of the basin.
65	Shiring-gawa	1.5	The basin is drained by one small stream, which is partially fed by seeps and springs issuing from	Shimajiri fine sand, highly dissected, underlies 20% of the basin. Limestone, located near the mouth of the stream, comprises 10%. The remainder is Shimajiri clay and has low relief.	Expanding towns, scrub growth, and grass cover much of the basin. Cultivation is restricted to the clay	Water is used locally by the natives.

Table 3. Description of drainage basins (continued)

			the limestone and Shimajiri silt and fine sand areas.		area.	
66	Machinato-gawa	2.6	Principal stream is the Machinato-gawa which draws from both surface water and seeps and springs flowing from the limestone areas. There may be some seepage of water from the limestone directly to the sea.	Limestone of low relief and flat to rolling surface covers 20% of the basin. The remaining 80% is Shimajiri clay and has moderate to high relief.	Expanding towns, and dry crops cover all but the steep slopes which are grass covered.	Same as above.
67	Hiya-gawa	2.2	A single stream drains the basin. Ground water may flow from the limestone under the limestone terraces to the north. The principal stream is largely fed in its lower course by one spring draining the limestone near Kakazu.	Limestone underlies 20% of the basin; the remainder is Shimajiri clay. The limestone areas near the lower course of the stream have low relief. In the upper part of the basin the clay area is moderately to highly dissected.	Cultivation is restricted because of steep slopes on the dissected clay and the stony limestone land.	The stream contributed to the pre-World War II Naha city water system.

Table 3. Description of drainage basins (continued)

No.	Major Stream Name	Area (in sq miles)	Drainage	Topography and Geology	Land Utilization	Water Utilization
68	Ohira-gawa	1.3	A single stream drains the basin. It is probably fed in part by seepage from Shimajiri silt and fine sand.	Shimajiri fine sand underlies 15% of the basin. The remainder is Shimajiri clay except for a small limestone area near the coast. The relief is low near the mouth, and moderate to high in the area of the headwaters.	High relief and the expansion of towns prevent much cultivation.	The stream is no longer used as a military water source.
69	Asha-kawa	4.0	The N and S forks of the Asha-kawa drain the basin and are fed by surface runoff and springs issuing from the limestone and fine sand areas. There is contamination by salt water in the tidal zone near the mouth.	Most of the basin is gray clay. Shimajiri fine sand occupies a small, moderately to highly dissected area (8%) in the northern part of the basin. Remnants of limestone cap some of the hills, and small areas of limestone are near the mouth of the basin. An upland surface of rounded hills and ridges rises inland.	Except for steep slopes left as grassland, the area is used for expanding towns and for cultivation.	Water point P-16 is located near the mouth of Asha-kawa.
70	Ikeda-gawa	1.2	The drainage consists of one short stream with several branches.	Most of the basin is Shimajiri fine sand, moderately to highly dissected. Some Shimajiri clay caps the sand around margins of the basin. Relief is moderate to high.	Cultivation is limited because of steep slopes which are grass covered. Some dry crops are grown on the gentle slopes.	Water point P-17 is located at the mouth of the basin. Water is diverted to fields on the coastal flats.

Table 3. Description of drainage basins (continued)

71	Asato-gawa	5.0	The Asato-gawa and its several tributaries drain the basin. Subsurface drainage of the limestone areas emerges as springs.	Limestone masses occur near the mouth of the Asato-gawa and cap two plateaus near Shuri. The remaining bedrock is Shimajiri gray clay. Minor amounts of Shimajiri fine sand occur east of Shuri.	In the limestone areas cultivation is limited because much of the area is occupied by native villages.	Military water points are no longer operated in this stream. The natives utilize chiefly springs and shallow wells.
72	Kokuba-gawa	7.9	Drainage is almost entirely surface. The N fork of the Kokuba-gawa has an estimated stream flow of 1,300,000 gpd. The S fork has an estimated stream flow of 650,000 gpd.	The basin is developed almost exclusively in Shimajiri clay. Broad valleys and intervening steep-sloped ridges and spurs have moderate relief. The lower reaches of the valley have a considerable thickness of alluvium.	Extensive cultivation of vegetables and other dry crops is practiced on all but the steeper slopes which are covered by coarse grass.	Used locally by the natives. Great seasonal variation in stream flow.
73	Nōha-kawa	5.8	One stream several miles long drains the basin. Drainage is predominantly surface. Small remnants of limestone near Taketomi and Shinzato discharge their ground water from springs.	This is predominantly an area of Shimajiri gray clay with small remnants of limestone capping some of the high ground on the margins of the basin. A broad valley is bordered by ridges with steep slopes and low spurs.	Dry crops are extensively cultivated. Paddies occur in the low areas which have sufficient water. Steep slopes are in grass.	Same as above.

Table 3. Description of drainage basins (continued)

No.	Major Stream Name	Area (in sq miles)	Drainage	Topography and Geology	Land Utilization	Water Utilization
74	Mukue-kawa	7.1	Most of the basin has a well-developed surface drainage that flows into the Mukue-kawa. Near Yoza the subsurface drainage of the limestone area emerges as a spring that considerably increases the flow of the stream.	Except for the area of limestone near Yoza, the Mukue-kawa drains an area of Shimajiri clay, with scattered limestone remnants near its mouth, at Itoman. The gray clay has a surface of low to moderate relief. Broad valleys are bordered by ridges with steep slopes and low spurs.	The low areas adjacent to the Mukue-kawa and its tributaries are largely in rice. Dry crops are grown over all but the steeper grass-covered slopes.	Yoza spring supplies water for irrigation as well as for the Integrated Island Water System.
75	Yuhi-gawa	6.0	Most of the area is drained by the Yuhi-gawa. It is fed partly by the slow movement of water from the paddy fields in the upper basin.	The lower course of the Yuhi-gawa flows through a broad, gently rolling limestone valley bordered by steep-pinnacled limestone slopes. Shimajiri clay underlies the upper part of the basin which consists of several gently rolling limestone plateaus.	Most of the land is in dry crops. Rice is grown in the low areas; scrub covers the steep limestone slopes; coarse grass covers the steep clay slopes.	All along the Yuhi-gawa some water is used to flood paddy fields.
76	Shiramizu-gawa	2.9	The principal surface drainage is one perennial stream which is fed by several springs draining the extensive limestone area. The limestone of the	Limestone underlies 70% of the basin. Shimajiri clay and tuff underlie 30%. The limestone surface is generally flat with characteristic pinnacles and ridges. Areas of clay are gently rolling and areas of tuff are moderately dissected.	The land is cultivated to dry crops and to rice in low areas. Steep slopes and rough limestone surfaces are grass covered.	Local water supply used by the natives.

Table 3. Description of drainage basins (continued)

			plateau has subsurface drainage which discharges from springs at the margins of the limestone.			

Corrosion and scale formation are controlled by feeding soda ash and polyphosphates, respectively at the treatment plants. Softening equipment has not been installed since parts per million of calcium carbonate ranges around 250. Military regulations require installation of softening equipment in treatment plants only if the water contains 400 or more ppm calcium carbonate. The spring-fed streams supplying Kue Treatment Plant and Futema-gawa illustrate the chemical composition of surface water from limestone and Shimajiri formation areas (table 7, Analyses of raw water from southern Okinawa).

The soft water in the southern part of the island is nonscale forming but very corrosive; therefore lime is used in the treatment plants to increase pH and hardness. The stream supplying the Yaka Treatment Plant (table 7) illustrates the chemical composition of surface water from the schist, phyllite, and sandstone areas.

Chlorine gas is introduced into the raw water as it enters the treatment plant (pre-chlorination) and again before leaving the plant (post-chlorination). The pre-chlorination dosage depends on the turbidity, the presence of organic matter, and the degree of pollution. Post-chlorination dosage is added to treated water to bring the chlorine residual up to the desired level before delivery to the distribution system.

Turbidity is higher in the streams of southern Okinawa than in the northern part of the island. However, it becomes a problem only in the short periods during and immediately after flash floods and during the more extended periods of flooding caused by typhoons.

The problem of pollution is very acute particularly in the Bishi-gawa basin and southward during and after floods, because there is no sewage control of the watersheds. The Futema-gawa intake point had to be abandoned because of gross pollution of the water at all times. The Futema-gawa drains a densely populated part of Okinawa.

Existing supplies

Surface-water sources which are used to supply the military and Naha city water systems as of 1957 are listed in Table 2. Tybase, Tengan, and Jaku Treatment Plants are designed to handle a total of 14,100,000 gpd with an overload capacity of 16,500,000 gpd. This amount is obtained from the streams in the Bishi-gawa and Tengan-gawa basins which discharge at three intake points a rough total of 16,500,000 gpd to 23,300,000 gpd. Intake points are discussed in Table 1.

The two small spring-fed streams that supply Kue Treatment Plant have relatively great seasonal fluctuations. Dry-season yield is 250,000 gpd per stream which is considerably below the 800,000 gpd capacity of Kue Treatment Plant. However, each stream discharges 1,200,000 gpd only during the wet season.

The stream that supplied Futema Treatment Plant has an estimated flow of 700,000 gpd and at all times supplied the 300,000 gpd which was the capacity of the plant. Severe pollution of the stream was responsible for the plant shutdown.

Yaka Treatment Plant has available at all seasons the 50,000 gpd

which is its maximum capacity. Dry-season discharge of the mountain-stream source is at least 60,000 gpd.

Okuma Treatment Plant with a design capacity of 140,000 gpd has a very good source in a stream which flows the year around at the rate of at least 5,000,000 gpd.

Easley Treatment Plant draws its water from a reservoir with a capacity of 93,000 cubic feet which itself is supplied by two streams. The Easley plant can handle no more than 100,000 gpd.

Problems of water impoundment

The major problems concerning the construction of reservoirs on Okinawa are centered around unsuitable foundation rock, lack of stream-gage data, and remoteness of suitable reservoir sites from cities and military-installation centers.

Areas of limestone, delineated on Plate 1, Ground-Water Map as Units 1, 2, and 3, are extremely unsuitable for the construction of reservoirs. Leakage would be rapid through fissures and caverns. Construction of reservoirs on the Tengan-gawa and the Bishi-gawa would be impractical except possibly at P-11 (pl. 5) and P-10. At site P-11 the Bishi-gawa flows across relatively impermeable phyllite. Careful mapping of the contact between areas of limestone and areas of phyllite and sandstone would be required to determine the size of a potential reservoir.

The most suitable site for a large reservoir in the Bishi-gawa basin, however, appears to be at P-10 where the Nagata-gawa is deeply incised in impermeable Paleozoic phyllite (table 1).

The site for the proposed Camp Hansen dam (P-3) is on sound Paleozoic rock. The upper part of the south wall of the reservoir is fissured limestone through which water would drain into the caves and caverns of the Kin area if the water level in the reservoir ever rose above the elevation of the limestone - schist, sandstone, and phyllite contact. Camp Hansen dam is planned to be 35 feet high in order to create a reservoir with capacity sufficient to furnish a marine camp with 2,240,000 gpd. This could be enlarged to provide 5,000,000 gpd.

The site for the proposed Henoko dam (P-4) is composed of sound and compact Paleozoic rock; all parts of the reservoir should be naturally watertight. The dam is to be 40 feet high and the reservoir is designed to supply 1,370,000 gpd to a marine camp. This could be enlarged to furnish 2,000,000 gpd. Both the Camp Hansen dam and the Henoko dam were in the planning stage at the time of writing in 1957.

The reservoir (P-2) for the Easley Treatment Plant is located in Paleozoic sandstone at the edge of sandy limestone. This reservoir with a capacity of 93,000 cubic feet was constructed by the Japanese about 1917 for sugar cane irrigation. In 1957 a hole developed near the dam. This was due to subsidence over a cavern which probably developed in limestone. Considerable leakage occurred through this hole in addition to some which was the result of faulty equipment.

Very low dams facilitate intake at most surface-water intake points and there usually is no impoundment. A small dam and reservoir

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(P-17) on a stream which has a flow of 15,000 to 30,000 gallons per day in high stage is located in the Shimajiri clay and fine sand northwest of Yonabaru. The reservoir is no longer used as a military water source, but it serves to show that the Shimajiri is suitable for reservoir construction. The water is now used by the natives for irrigation.

The most serious lack of information for use in construction of any reservoir in Okinawa is data regarding stream flow over a period of years. Stream-gage data are vitally important in determining size of reservoir required. The data are needed also in planning control of water usage because of the very great variation of flow from month to month, year to year, and even from place to place.

Northern Okinawa is well suited to the construction of reservoirs because of its vast areas of tight Paleozoic rock and steep-walled valleys. However, the cost of piping water from northern Okinawa to southern Okinawa would be extremely high. Reservoirs in basins north of the Tengan-gawa and Bishi-gawa would probably be used merely to supply adjacent installations.

Ground Water

Quantity and distribution

At least 200,000 gallons of fresh water per day are available from single wells drilled in limestone, gravel, and sand in the two areas delineated as Map Unit 1 (pl. 1, Ground-water map). One of these areas is the Tengan-Tybase-Kadena Airbase region where wells would be easily accessible to pipelines of the Integrated Island Water System. The second area is in the Easley Range-Chimmu Airfield region where existing and proposed reservoirs (P-2 and P-3) are expected to take care of the needs of military installations.

Up to 75,000 gpd of fresh water may be obtained from each well drilled in limestone near the coast. The most extensive of these areas, delineated as Map Unit 2, are north of Katchin-hantō and south of Zampa-misaki. Wells will produce more than 75,000 gpd, but the water is apt to become brackish.

Elsewhere in widespread limestone areas, mapped as Unit 3, amounts of water are extremely variable. Springs are very common and yields range from a few gallons to several million gallons per day. Wells are generally not as feasible to develop as springs. Success of a well depends on the chance striking of a trunk cavern receiving widespread subsurface drainage.

Quantities of fresh water are also available from shallow dug wells, infiltration galleries in stream alluvium, and beach deposits mapped as Map Unit 4. Yields are generally small, but a few wells will produce as much as 100,000 gpd. Areas of beach deposits are more extensive in southern Okinawa, and areas of stream alluvium are more abundant in northern Okinawa.

Most of the Shimajiri formation (map unit 5), that extends from Katchin-hantō southward, is a compact clay that will not yield water to wells. However, up to 30,000 gpd may be obtained from large-diameter dug wells in local beds of silt and fine sand. In the Naha city

Impermeable phyllite is crossed by the Bishi-gawa. This is one of the few areas on the Bishi-gawa suitable for construction of reservoirs. View east. March 1957.

area and a few other localities single wells more than 250 feet deep may produce 100,000 gpd or more of fresh water from sand and gravel.

Less than 10,000 gpd can generally be expected from single wells in the Paleozoic schist, sandstone, and phyllite (map unit 6) that characterize the island north of Kadena Airbase. Locally, in areas of fracture, yields may be as much as 30,000 gpd. The selected wells shown on Plate 1, Ground-Water Map are described in Table 5.

There are many springs on Okinawa. Those in northern Okinawa are usually located in zones of fracture and along cliffs at the base of limestone. Little is known about yields of these springs which are generally undeveloped owing to the accessibility of more easily developed surface-water sources. In southern Okinawa many springs have been developed primarily for native domestic use. Two water-treatment plants, however, use springs exclusively for their water sources. Yields show a great variability from 4,000,000 gpd during high stage at S-4 to nothing at some springs during dry periods. Springs are generally located at the base of or in limestone in southern Okinawa. The selected springs shown on Plate 1, Ground-Water Map and described in Table 6, are located primarily in Map Unit 3 and along the boundary of Map Unit 3 and Map Unit 5. Although many others exist elsewhere, this is the area most suited for the development of springs.

Quality

Water from the limestone areas (map units 1, 2, and 3) is polluted with harmful bacteria except in deep-drilled wells. It is clear in wells and most springs, but some spring water is turbid after heavy rains. The water is typically hard as shown by Table 7, Analyses of Raw Water from Southern Okinawa. The shallow well (W-10) at Okinawa Motors, the two deep Napunja wells (W-1 and W-2), and Yoza spring (S-3) serve to illustrate the chemical quality of water from aquifers above sea level in the limestone areas. These four ground-water sources have a range of various constituents as follows:

	Minimum	Maximum
	(in parts per million)	
Total solids	250	538
Total hardness as $CaCO_3$	195.5	288
Calcium (Ca)	70	105
Magnesium (Mg)	1.8	14
Iron (Fe)	0.00	0.05
Sodium (Na)	15	53
Sulfate (SO_4)	2	15
Chloride (Cl^-)	28	92
Carbonate (CO_2)	7	28
Silicate (SiO_2)	0.1	7
Aluminum oxide (Al_2O_3)	0.00	0.04
pH	7.1	7.3

Yontan well draws its water from a basal-water source at and below sea level. Except for slightly more SO_4, the water from this well in the limestone of Map Unit 2, falls within the above ranges while not more than 75,000 gpd are being pumped. Samples taken while more than 75,000 gpd are being pumped show that total solids increase from 383 to 654 ppm; sodium increases from 51 to 97 ppm, and chloride increases from

Table 5. Selected wells in southern Okinawa

Locations of these wells are shown on Plate 1, Ground-Water Map. The coordinates are Universal Transverse Mercator grid references and may be found on AMS L791, Ryūkyū-rettō, 1:50,000. The abbreviation n.d. means data not available, n.a. means not applicable, gpd means gallons per day, and GRI means Government of Ryukyu Islands.

Number	Name or Location	Coordinates	Aquifer	Depth (in ft)	Quantity (in gpd)	Quality	Comments
W-1	Napunja well No. 1	CE 825158	Limy sand and gravel	91	>200,000	Fresh, clear, very hard, unpolluted	Surface elevation about 160 ft above sea level. Aquifer is about 69 ft above sea level. Size of pump limits production to 200,000 gpd. Tied into Integrated Island Water System. Water is used to supply Camp Hague.
W-2	Napunja well No. 2	CE 821161	Limy sand and gravel	87	>200,000	Fresh, clear, very hard, unpolluted	Surface elevation about 160 ft above sea level. Aquifer is about 73 ft above sea level. Size of pump limits production to 200,000 gpd. Tied into Integrated Island Water System. Part of Camp Hague water supply.
W-3	Wash-rack well in taxiway Q, Kadena Airbase.	CE 780145	Limestone	152	>200,000	Fresh, clear, very hard, unpolluted	Surface elevation about 195 ft above sea level. Aquifer is about 43 ft above sea level. Capacity of pump limits production to 200,000 gpd. Water is used to wash airplanes.
W-4	Motor-pool well at Kadena Airbase located 200 to 250 ft SW of motor-pool gas pumps.	CE 778135	Limestone	160	>200,000	Fresh, clear, very hard, unpolluted	Surface elevation about 200 ft above sea level. Aquifer is about 40 ft above sea level. Capacity of pump limits production to 200,000 gpd. Water used to wash vehicles.
W-5	Yontan well	CE 734190	Limestone	90	>75,000	Fresh, clear, very hard	Surface elevation 80 ft; bottom of well 10 ft below sea level. Pumping in excess of 75,000 gpd induces salt-water intrusion.

Table 5. Selected wells in southern Okinawa (continued)

W-6	Well NW of Katena	CE 740176	Underground channel in limestone	20	n.d.	Fresh, clear, very hard	Large yield all year, but less than 1,000,000 gpd. Information from Civil Engineer Section, Public Services Dept., GRI.
W-7	Sobe well	CE 744169	Limestone	60	60,000	Fresh, clear, very hard	Surface elevation 50 ft above sea level; bottom of well 10 ft below sea level. Capped; to be used in an emergency.
W-8	Well S of Ūgi and N of Katena	CE 752175	Underground channel in limestone	80	48,000	Fresh, clear, very hard	Bottom of well 10 ft above sea level. Supplies Ūgi village. Information as of Feb. 1, 1957.
W-9	Miwa-son well	CD 737865	Underground channel in limestone	65	Not measured	Fresh, clear, very hard	Purpose of drilling was to tap channel of spring on face of sea cliff. Yield not measured but expected to be large. Not used because of need for airlift pump. Information from Land Development Section, GRI.
W-10	Dug well at Okinawa Motors	CE 695026	Base of limestone on Shimajiri	37	10,000	Fresh, clear, very hard	Diameter is 12 ft. Eighteen feet of water stands in well; leaks through limestone above this level. Water used to wash vehicles. Use 6,000 to 8,000 gpd.
W-11	Well on Katchin-hantō W of Heshikiya	CE 916096	Limestone but not at the base	80	40,000	Fresh, clear, very hard	Information as of Feb. 1, 1957.
W-12	FBIS well on Bolo peninsula	CE 735226	Channel in limestone	85	19,400	Fresh, clear, very hard	Surface elevation about 135 ft above sea level. Bottom elevation about 50 ft above sea level.

Table 5. Selected wells in southern Okinawa (continued)

Number	Name or Location	Coordinates	Aquifer	Depth (in ft)	Quantity (in gpd)	Quality	Comments
W-13	Test boring for well	CE 736228	none	80	Dry hole in lime-stone	n.a.	Bored with 8-in. bit. Surface elevation 143 ft. Bottom of hole 63 ft above sea level.
W-14	Test boring for well	CE 737226	none	185	Dry hole in lime-stone	n.a.	Bored with 8-in. bit. Surface elevation 152 ft. Bottom of hole 33 ft below sea level.
W-15	Tsukazan well	CE 712963	Alluvium on stream bank	About 5 to 8	n.d.	Same as stream water	Dug well at least 12 ft in diameter. Used as village well.
W-16	Gallery well N of Nakatomari village	CE 809252	Beach sand	Very shallow	100,000	Fresh	Gallery is 200 ft long at sea level. Pumping more than 100,000 gpd would probably bring in salt water. No longer used as military water point.
W-17	Native dug well at Military Recreation Beach	CE 832230	Beach sand	10	20,000	Fresh	Well is 10 ft long and 4 ft wide. Used as the source for the Ishikawa Treatment Plant. Contaminated by salt water as the result of typhoon "Emma", 1956; clearing slowly.
W-18	Naha Airbase wells (two)	CD 672981 CD 672980	Shimajiri silt	167 200	Each well produced 39,000 (low reliability)	Fresh	Both wells were sited about 100 ft above sea level. Now abandoned and covered by housing development.
W-19	Catholic Mission well at Shuri	CD 728992	Shimajiri fine sand	265	Probably will produce 1,000	Fresh, clear, hard	Well has 6-in. casing. Waiting for airlift pump (March 1957). Information from Land Development Section, GRI.

Table 5. Selected wells in southern Okinawa (continued)

					to 14,000		
W-20	Well at Yakena on Katchin-hantō	CE 913111	Shimajiri black sand under clay slate	300	18,720	Brackish, natural gas	Well has 1½-in. casing. Surface elevation 20 ft above sea level. Water too brackish for drinking.
W-21	Well at Kanegusuku	CD 679907	Shimajiri sand	550	n.d.	Brackish	Drilled in June 1955.
W-22	Sugar Mill well at Kaneku	CD 767996	Shimajiri sand	700	115,000	Brackish, natural gas	Casing 3 in. in diameter. Water used for cooling purposes in condensers.
W-23	Kokuei Kan Theater well at Naha	CD 684994	Coarse-grained sand in Shimajiri	586	230,000	Brackish, natural gas	Water is used for the air-conditioning system. The natural gas is used for cooking in the theater restaurant. Well has 8-in. diameter casing and strainers for all sand layers.
W-24	Drilled well for Okinawa Motors	CE 695026	Fine-grained black sand in Shimajiri	500	100,000	Reported good drinking	Well has 2-in. casing to 300 ft. Waiting for airlift pump (March 1957). Some caving has been reported below casing.
W-25	Well for Ryukyu Meat Co. at head of Kokuba bay	CD 697971	Sand and gravel in Shimajiri under heavy blue clay	426	Not measured	Reported good drinking	Well has 3-in. casing. Water used in meat packing.

Table 5. Selected wells in southern Okinawa (continued)

Number	Name or Location	Coordinates	Aquifer	Depth (in ft)	Quantity (in gpd)	Quality	Comments
W-26	Ishibashi well on Highway 11 near mouth of Nōha-gawa	CD 691963	Black sand under blue clay and over rock too hard to penetrate	468	Not measured but reported greater yield than W-25	Reported good drinking	Well has 6-in. casing to 300 ft. Drill was weighted with 700 lb. Water is used for irrigation of vegetable farms.
W-27	Well on Highway 44 at mouth of Kokuba-gawa	CD 699974	Buff-colored sand over rock too hard to penetrate	250	Not measured. Flowing artesian well	Reported good drinking	Well has 1½-in. pipe in 4-in. casing. Drilled Nov. or Dec. 1956 for farming and household uses.
W-28	Sake Mill well on Highway 68 S of Jiha	CD 669951	Sand over rock too hard to penetrate	375	Not measured. Flowing artesian well	Good quality chemically	Well has 1½-in. pipe all the way down. Used for making sake. A second similar flowing artesian well is used for irrigation.
W-29	Dry hole at Shimabuku	CE 800117	none	680	Dry and abandoned. In Shimajiri clay	n.a.	Found a little water at the base of the limestone at a depth of 80 ft. Ceased drilling in Shimajiri blue clay.
W-30	Yakada well	CE 843281	Paleozoic schist formation	164	8,750	Fresh, soft to moderately hard, moderately corrosive	Well has 6-in. casing to depth of 43.5 ft. Surface elevation 125 ft above sea level. Bottom of well is 39 ft below sea level. Water table 70 ft above sea level.

Table 5. Selected wells in southern Okinawa (continued)

W-31	Tengan well	CE 841195	Paleozoic schist formation	155	34,500	Fresh, soft to moderately hard, moderately corrosive	Bored with 8-in. bit. Cased to depth of 64.7 ft. Surface elevation 240 ft above sea level. Bottom elevation 85 ft above sea level. Water table 168 ft above sea level.
W-32	Two wells at Futema	CE 789081	Base of limestone on Shima-jiri clay	70	> 1,000	Very hard	
W-33	Well at Odo	CD 703862	Under-ground cavern in limestone	Very shallow	Not meas-ured	Very hard	This is a tunnel made in an attempt to make the water of a spring more easily accessible.

Table 6. Selected springs in southern Okinawa

Location of these springs are shown on Plate 1, Ground-Water Map. The coordinates are Universal Transverse Mercator grid references and may be found on AMS L791, Ryūkyū-rettō, 1:50,000. The abbreviation n.d. means data not available, gpd means gallons per day, and GRI means Government of Ryukyu Islands.

Number	Name or Location	Coordinates	Quantity (in gpd)	Aquifer	Comments
S-1	Maedaira spring	CD 708876	1,063,000	Base of limestone	Used for general purposes in dry weather. High turbidity prevents use after rains. Information from GRI files - Survey for Irrigation Development, November 1953.
S-2	Shikiya spring on cliff above village. Also called spring at Chinen Treatment Plant.	CD 800924	2,088,000; may drop as low as 500,000	Base of limestone	Originally was used by the natives for drinking and hydroelectric power. Now under U.S. Forces supervision and supplies water for Chinen Treatment Plant.
S-3	Yoza spring	CD 702902	1,500,000; may drop as low as 500,000	Base of limestone	This spring is tied into the Integrated Island Water System.
S-4	Mabuni springs (two) located approximately 60 ft apart at base of sea cliff.	CD 737868	Combined yield 4,000,000; may drop as low as 1,000,000	Limestone	The springs flow to the sea and are too inaccessible for use by the natives.
S-5	Mēgā spring	CD 756910	1,615,000	Base of limestone	Used by the natives for irrigation. Information from GRI files - Survey for Irrigation Development, November 1953.
S-6	Spring S of Futema-gawa	CE 766076	1,293,000; may drop as low as 646,000	Base of limestone	Used by natives for drinking. Information from Civil Engineer Section, Public Services Dept., GRI, February 1957.

Table 6. Selected springs in southern Okinawa (continued)

S-7	Spring on banks of the Bishi-gawa	CE 758163	1,000,000	Limestone	Information as of February 1957.
S-8	Ōsato spring	CD 694898	865,000	Base of limestone	Used for drinking even in rainy periods. It is not as muddy then as Maedaira spring (S-1). Information from GRI files - Survey for Irrigation Development, November 1953.
S-9	Spring S of Itoman	CD 675891	870,000	Base of limestone	Used for irrigation. Source of information as above.
S-10	Kohagura spring	CD 675875	870,000	Limestone	Not in use because of inaccessibility. Water is in natural tunnel at bottom of steep-sided sinkhole 60 ft deep. Source of information as above.
S-11	Komesu-kaigan spring	CD 703854	969,000	Limestone	Used for domestic purposes except at high tide. Flows to the sea from limestone ledge.
S-12	Spring near the junction of Highways 1 and 30	CE 759071	504,000 to 1,000,000	Base of Limestone	One of the principal water points for the Naha City Treatment Plant.
S-13	Kin spring	CE 936257	1,000,000; may drop as low as 200,000	Limestone	Source for Kin village.
S-14	Spring N of Goeku	CE 817147	500,000 year around	Base of limestone	Used for drinking. Information as of February 1957.
S-15	Spring at Gushikawa	CE 874147	n.d.	Base of limestone	Used for drinking. The yield had not been measured, but the spring flows all year around.

Table 6. Selected springs in southern Okinawa (continued)

Number	Name or Location	Coordinates	Quantity (in gpd)	Aquifer	Comments
S-16	Spring called Akazan-gawa	CE 874157	n.d.	Base of limestone	Reported to be one of the two best springs in the area.
S-17	Spring called Nuri-gawa	CE 858162	n.d.	Base of limestone	Reported to be one of the two best springs in the area.
S-18	Spring near Ōsato spring (S-8)	CD 695900	323,000	Limestone	Used for drinking and irrigation. Information from GRI files - Survey for Irrigation Development, November 1953.
S-19	Spring SE of Kuniyoshi and SE of Itoman	CD 687888	336,000	Limestone	Used for irrigation. Source of information as above.
S-20	Spring near Kuniyoshi spring	CD 688887	258,000	Limestone	Used for irrigation. Source of information as above.
S-21	Spring S of Itoman	CD 661860	194,000	Limestone	Used for drinking and irrigation. Source of information as above.
S-22	Spring at Aragaki S of Ōsato	CD 698886	128,000	Limestone	Used for drinking. Source of information as above.
S-23	Spring E of Naagusuku	CD 680873	484,000	Limestone	Not in use because of inaccessibility. Water is in an underground channel at the bottom of a sinkhole. Source of information as above.
S-24	Spring S of Makabe	CD 698865	194,000	Limestone	Used for drinking. Spring is in an underground channel. Source of information as above.
S-25	Spring E of Yamagusuku	CD 688856	323,000	Limestone	Used for general purposes by the natives. Source of information as above.

Table 6. Selected springs in southern Okinawa (continued)

S-26	Spring at Nakaza	CD 735884	258,000	Limestone	Used for drinking and irrigation. Source of information as above.
S-27	Spring S of Aragusuku	CD 745906	194,000	Limestone	Not in use. Source of information as above.
S-28	Spring NE of Gushichan	CD 750895	129,000	Limestone	Not in use. Source of information as above.
S-29	Spring S of Itokazu	CD 762922	258,000	Limestone	Used for drinking and irrigation. Source of information as above.
S-30	Military Government spring	CD 800924	250,000; may drop as low as 75,000	Base of limestone. In underground channel	No longer used as a military water source.
S-31	Spring at Yamazato	CD 808928	129,000	Limestone	Used for drinking and irrigation. Information from GRI files - Survey for Irrigation Development, November 1953.
S-32	Spring at Yamazato	CD 807927	323,000	Limestone	Used for drinking and irrigation. Source of information as above.
S-33	Spring W of Chinen	CD 814932	194,000	Limestone	Used for drinking and irrigation. Source of information as above.
S-34	Spring near Chinen	CD 812940	194,000	Limestone	Used for drinking and irrigation. Source of information as above.
S-35	Spring covered by Highway 1, SW of the junction of Highways 1 and 30	CE 756069	222,000	Base of limestone	Abandoned due to road construction. Water had been used by natives.

Table 6. Selected springs in southern Okinawa (continued)

Number	Name or Location	Coordinates	Quantity (in gpd)	Aquifer	Comments
S-36	Spring covered by Highway 1, SW of the junction of Highways 1 and 30	CE 759067	125,000	Base of limestone	Abandoned due to road construction. Water was used by natives.
S-37	Spring W of Uchidomari and N of Highway 1	CE 748065	222,000	Base of limestone	One of the principal sources for the Naha City Treatment Plant.
S-38	Teruyagawa spring near hospital N of Machinato	CE 740060	161,000	Base of limestone	Used by the natives for general purposes.
S-39	Hitotsu-gawa spring SW of hospital	CE 740056	207,000	Base of limestone	One of the principal sources for the Naha City Treatment Plant.
S-40	Arakawa spring SW of hospital	CE 739054	200,000	Base of limestone	Abandoned. Had been used by the natives for general purposes.
S-41	Futema Airstrip spring	CE 748048	100,000	Limestone. In channel at bottom of sinkhole	Has been considered as a possible supplementary source for Naha City Treatment Plant.
S-42	Kushibaru-gawa spring S of Highway 1, SE of Machinato	CE 738048	295,000	Base of limestone	One of the principal sources for the Naha City Treatment Plant.
S-43	Machinato-gawa spring S of Machinato	CE 732045	175,000	Base of limestone	One of the principal raw-water sources for the Naha City Treatment Plant.
S-44	Spring near Kawasaki Pump Station	CE 852181	>100,000	Limestone	Drains into Tengan-gawa and is used as a source for Tengan Treatment Plant.

Table 6. Selected springs in southern Okinawa (continued)

S-45	Spring W of Highway 13 near Hizaonna	CE 830205	120,000	Between the base of the limestone and the underlying phyllite	One of the best springs in the region. No longer used as a military water point.
S-46	Spring at Yoshitomi	CD 821943	129,000	Base of limestone	Used for drinking and irrigation. Information from GRI files - Survey for Irrigation Development, November 1953.
S-47	Spring at Shuri	CE 716001	100,000	Base of limestone	Considered as a possible supplementary source for Naha City Treatment Plant.
S-48	Spring W of Highway 146 and S of Highway 30	CE 801084	n.d.	Base of limestone	Supplies the villages of Kishaba and Chunjun and paddy fields.
S-49	Spring covered by Highway 1, SW of the junction of Highways 1 and 30	CE 755068	68,000	Base of limestone	Abandoned. Before road construction it had been used by the natives for general purposes.
S-50	Oyama-gawa spring near hospital NE of Machinato	CE 742062	68,000	Base of limestone	Abandoned.
S-51	Spring S of Itoman	CD 669878	64,500	Limestone	Used for irrigation. Information from GRI files - Survey for Irrigation Development, November 1953.
S-52	Spring NE of Itokazu	CD 768927	51,500	Limestone	Used by natives for general purposes. Source of information as above.
S-53	Spring W of Oyakebaru	CD 776932	84,000	Underground channel in limestone	Used for drinking. Source of information as above.

Table 6. Selected springs in southern Okinawa (continued)

Number	Name or Location	Coordinates	Quantity (in gpd)	Aquifer	Comments
S-54	Spring at Hyakuna	CD 796914	97,000	Limestone	Used for drinking. Source of information as above.
S-55	Spring at Yoshitomi	CD 820944	64,500	Limestone	Used for drinking. Source of information as above.
S-56	Spring near Chinen	CD 816934	50,000	Limestone	Used for drinking. Local residents report a good flow all year. Source of information as above.
S-57	Two springs at Hantaga	CD 718991	>36,000	Base of limestone	The yield is the amount pumped from the combined wells in February 1957. Supplies Hantaga village and vegetable gardens producing crops for U. S. Forces in the Far East.
S-58	Spring near the Yoza spring	CD 697904	19,500	Base of limestone	Used for irrigation. Information from GRI files - Survey for Irrigation Development, November 1953.
S-59	Spring S of Aragaki	CD 696882	35,000	Base of limestone	Used for irrigation. Source of information as above.
S-60	Spring at Makabe	CD 697873	26,000	Underground channel in limestone	Used for drinking. Source of information as above.
S-61	Spring S of Toei	CD 703875	35,000	Underground channel in limestone	Used for drinking. Source of information as above.
S-62	Spring S of Aragusuku	CD 746904	35,000	Limestone	Not in use. Source of information as above.

Table 6. Selected springs in southern Okinawa (continued)

S-63	Spring S of Shinzato	CD 775941	7,000 to 10,000	Limestone	No longer used as a military water source.
S-64	Spring SE of Yoza spring	CD 705900	4,200	Limestone	Used for drinking. Information from GRI files.
S-65	Spring E of Ōsato	CD 701895	4,200	Limestone	Used for drinking. Information from GRI files.
S-66	Spring N of Gushichan	CD 747898	600	Limestone	Not in use. Information from GRI files.
S-67	Spring at Gushichan	CD 749891	n.d.	Base of limestone	Used for general purposes by the natives.

Table 7. Analyses of raw water from southern Okinawa

The testing by the Central Laboratory, U. S. Army Engineer Group, Sanitation Section. Points in column 1 shown on Plate 1, Ground-Water Map. Symbols used: gpd, gallons per day; dash (-), not tested.

Well, Spring, or Stream Intake Number	Source of Water	Kind of Rock Producing Water or Kind of Rock Over Which Stream Flows	Total Solids	Alkalinity		Total Hardness as $CaCO_3$	pH	Constituents in parts per million											
				Phenolphthalein as $CaCO_3$	Methyl Orange as $CaCO_3$			Ca	Mg	Fe	Mn	Na	SO_4	Cl	CO_2	SiO_2	Al_2O_3	PO_4	F
P-13 A and B	Streams supplying Kue Plant	Limestone in contact with Shimajiri clay	422	0	284	314	7.2	116	6	0.05	0.0	23	6	48	37	8	0.4	-	0.15
W-10	Well at Okinawa Motors	Limestone at contact with Shimajiri clay	538	0	268	288	7.3	99	10	0.05	0.0	53	15	92	27	5	0.04	-	-
S-3	Yoza spring	Cavernous limestone	250	0	174	195.5	7.3	70	5	0.05	0.0	15	4	28	18	5	0.0	-	0.1
W-1	Napunja well No. 1	Limy sand and gravel	379	0	274	270	7.1	105	1.8	0.0	0.0	23	13	45	7	0.1	0.1	0.1	0.1
W-2	Napunja well No. 2	Limy sand and gravel	315	0	220	237	7.2	72	14	0.05	0.0	17	2	38	28	7	0.1	-	0.08
	Futema-gawa	Limestone. Shimajiri sand and clay	355	6	207	224	8.3	78.5	6.6	0.15	0.0	32.4	32	44	1.8	9	0.26	0.05	0.2
W-5	Yontan well. Pumping rate at time of sampling:	Limestone, 10 ft below sea level A	654	0	203	275.1	7.2	92	11	0.08	0.0	97	25	198	26	8	2.2	0.1	0.3

Table 7. Analyses of raw water from southern Okinawa (continued)

W-5 (cont.)	A More than 75,000 gpd B Less than 75,000 gpd B		383	0	204	216	7.2	78	5	0.1	0.0	51	19	89	26	9	0.0	-	0.1
W-17	Well for Ishikawa Plant	Alluvium and beach deposits	721	0	350	396	7.3	112	28	0.0	0.0	64	56	100	35	17	Tr	Tr	0.5
W-28	Sake Mill well	Sand at base of Shimajiri	575	0	322	256	7.1	83	12	0.6	Tr	103	21	125	52	12	-	-	-
W-27	Well at mouth of Kokuba-gawa	Sand at base of Shimajiri	1105	16	326	21	8.5	5	2	0.3	0.0	412	5	450	2	12	-	-	-
W-26	Ishibashi well	Sand at base of Shimajiri	1590	8	446	20	8.3	6.4	1	0.05	0.0	615	31	680	4.5	18	0.0	-	-
W-25	Wells for Ryukyu Meat Company	Sand and gravel at base of Shimajiri	1510	16	410	20	8.4	5.2	1.7	0.05	0.0	580	29	640	3	18	0.0	-	-
W-23	Kokuei Kan Theater well	Coarse-grained sand in Shimajiri	3300	0	596	61	7.9	19	3	0.1	0.0	1215	50	1600	I5	15	0.7	-	-
P-12	Stream supplying Yaka Plant	Paleozoic schist formation	127	0	24	30	7.2	4	5	0.2	0.0	28	5	46	3	16	0.8	-	0.1
W-30	Yakada well	Paleozoic schist formation	331	0	116	106.5	6.7	18	15	-	-	61	20	92	46	40	-	Tr	0.3
W-31	Tengan well	Paleozoic schist formation	202	0	52	33	6.2	5.8	4.5	-	-	24	8	46	35	-	-	0.1	0.15

89 to 198 ppm. These increases are interpreted to mean the start of sea-water intrusion. Wells such as the Yontan well, when affected by salt-water intrusion due to overpumping, show an increase in the sulphate-chloride ratio to approximately the same sulphate-chloride ratio normal to Pacific Ocean water. The ratio of calcium to other salts in the affected Yontan well is higher than that in sea water.

The well supplying Ishikawa Treatment Plant illustrates the chemical quality of the water of Map Unit 4 (table 7). Its content of total solids, 721 ppm, is higher by at least 200 ppm than the total-solids content of water samples from aquifers above sea level in the limestone areas. Compared with these samples, the Ishikawa well water is high in total hardness as $CaCO_3$, Ca, Mg, Na, SO_4, Cl, CO_2, and SiO_2.

Samples of water taken from wells tapping sand and gravel aquifers at the base of the Shimajiri formation in, south, and southeast of Naha City show distinct differences in composition from one locality to another. They also show a distinctly different chemical composition from water samples taken from wells tapping aquifers at and above the top of the Shimajiri formation. Water from the Sake Mill well (W-28) is the best quality of any tested from the base of the Shimajiri. In most respects its composition compares with that of water in Map Units 1, 2, 3, and 4. Although higher in sodium (103 ppm) and chlorine (125 ppm) these constituents are well within the limits of U. S. Public Health Service standards. The Ishibashi well (W-26), the well for Ryukyu Meat Company (W-25), and the Kokuei Kan Theater well (W-23) have, of the wells tested, the highest content of total solids, sodium, and chlorine (table 7). This water may be in part connate water from the Shimajiri formation (that is the water trapped in the sediments while they were being deposited and not entirely flushed out by rainwater). According to the ratio of chloride to sulphate in Pacific Ocean water, these three wells should have between 3 and 4 times more sulphate if the high chloride content were due to salt-water intrusion. On the same basis the ratio of calcium to the other salts should also be 2 or 3 times higher than exists in these three wells. The ratio of magnesium to chloride is much lower than could be expected if salt-water intrusion had taken place.

Water from the Kokuei Kan Theater well (W-23) at a depth of 586 feet (table 8) is brackish and associated with natural gas. The water is used for the air-conditioning system and the natural gas is used for cooking in the theater restaurant. The water from Sugar Mill well at Kaneku (W-22) in Shimajiri sand at a depth of 700 feet also is brackish and associated with natural gas. The water is used for cooling purposes in the sugar mill condensers. Natural gas is associated with brackish water at a depth of 300 feet in black sand of the Shimajiri formation at the Yakena well in Katchin-hantō (W-20). The water from the well at Kanegusuku (W-21) in Shimajiri sand at a depth of 550 feet is also brackish.

Wells in the basal sand and gravel of the Shimajiri which are reported by the Okinawans as good for drinking are: the drilled well 500 feet deep for Okinawa Motors (W-24); the Ryukyu Meat Co. well (W-25) 426 feet deep; the Ishibashi well (W-26) 468 feet deep, used for irrigating vegetable farms; the well on Highway 44 at the mouth of Kokuba-gawa (W-27) 250 feet deep, used for farming and household purposes; and the Sake Mill well (W-28) 375 feet deep, used for making sake.

Table 8. Subsurface layers occurring in selected wells in Okinawa
The locations of wells are shown on Plate 1, Ground-Water Map.

Name and Number Drillers Log	Depth (in ft)	Age or Formation
Wash-rack Well (W-3)		
Clay	0 - 8	Pliocene and Pleistocene limestone
Light brown sandy limestone	8 - 92	
Light buff porous limestone; compact limestone	92 - 151	
Miwa-son Well (W-9)		
Clay	0 - 3	Pliocene and Pleistocene limestone
Coral limestone	3 - 65	
Catholic Mission Well (W-19)		
Red clay	0 - 10	Pliocene and Pleistocene limestone
Coral limestone	10 - 20	
Gray clay slate	20 - 120	Shimajiri
Coral limestone	120 - 125	
Brown sandstone	125 - 225	
Sand	225 - 265	
Well has 6-in. casing. Water rose 65 ft.		
Kokuei Kan Theater Well (W-23)		
Red clay	0 - 18	Shimajiri
Gray clay slate	18 - 33	
Black sand	33 - 38	
Gray clay slate	38 - 123	
Fine black sand	123 - 128	
Gray clay slate	128 - 238	
White sand	238 - 246	
Clay slate	246 - 496	
Sand	496 - 506	
Clay slate	506 - 556	
Coarse-grained sand	556 - 586	
Water rose to within 50 ft of the surface when sand at 496 to 506 ft was penetrated; gas in this horizon. Water rose to within 5 ft of the surface when bottom coarse-grained sand was penetrated; gas also in this horizon.		
Okinawa Motors Well (W-24)		
Red clay and limestone	0 - 50	Pliocene and Pleistocene limestone
Clay slate	50 - 450	Shimajiri
Fine black sand	450 - 500	
Lost water in 0- to 50-ft limestone layer.		
Sake Mill Well (W-28)		
Gray shale	0 - 50	Shimajiri
Red clay	50 - 150	
White sandstone	150 - 320	
Sand	320 - 375	
Hard rock; cannot be penetrated	375 -	Pre-Shimajiri

The soft to moderately hard and very corrosive water from the Paleozoic schist, sandstone, and phyllite, so prevalent in northern Okinawa, is represented in the Yakada well (W-30) and the Tengan well (W-31, table 7). The Yakada well has a total hardness as $CaCO_3$ of 106.5 ppm; its pH is 6.7 and Ca is 18 ppm. The Tengan well has a total hardness as $CaCO_3$ of only 33 ppm; its pH is 6.2 and Ca is 5.8 ppm.

Map unit 1

Location and accessibility: Two areas are included within the delineation of Map Unit 1 (pl. 1, Ground-water map). The first lies just east of Easley Treatment Plant and includes the village of Kin and Chimmu Airfield. The second is a belt extending from the Tengan Treatment Plant south through the Napunja and Tybase Treatment Plants to Kadena Airbase. Wells and springs in either area would be accessible to military water plants and pipelines.

Geological conditions: The Easley Range-Kin area consists of permeable limestone resting on less permeable sandstone. The surface is 130 to 190 feet above sea level and the bottom of wells should penetrate aquifers 30 to 40 feet above sea level. The rock structure of the Tengan-Katena area appears to be a trough filled with porous limestone, gravel, and sand. This material rests on relatively impermeable rocks which crop out to the south as the clay of Map Unit 5 and which crop out to the north as the phyllite, sandstone, and schist of Map Unit 6. The ends of the trough are open to the East China Sea on the west and the Pacific Ocean on the east. Ground water percolates through the pores or flows in fissures and solution cavities toward the sea at either end. Water movement is hampered by faults which bring aquifers to a dead end against impermeable rock and divert direction of flow along the lines of displacement.

Springs: Of the 7 springs listed in Table 6 as yielding between 500,000 and 1,000,000 gpd (gallons per day), 2 are within the area of Map Unit 1. One, the Kin spring (S-13), drains a portion of the limestone terrace on which the town of Kin and the airfield are built. Located on the southern border of the Easley Range-Kin area, it is a water source for Kin village. It has a large seasonal variation with a yield of 200,000 to 1,000,000 gpd. The other is S-14, located north of Goeku, on the south-central border of the Tengan-Katena area, and drains the base of limestone. This spring yields 500,000 gpd all year. Although other springs occur in this map unit, especially along the borders, these two are the only ones that are shown on Plate 1.

Wells: No wells are listed for the Easley Range-Kin area. The two Napunja wells (W-1 and W-2) and the two Kadena Airbase wells (W-3 and W-4) are typical of the type of wells which could be expected by drilling in the Tengan-Katena area. They are 90 to 160 feet deep and draw water from aquifers 90 to 200 feet below the surface of the ground and 40 to 70 feet above sea level. Design of the pumps at each well limits yield to about 200,000 gpd.

Well siting and drilling problems: The most favorable sites for potential wells are in the centers of the unit areas. Several test holes would have to be drilled to locate the best aquifers since wells tapping subterranean channels will provide greatest yields. Drilling should cease as soon as the underlying Paleozoic schist, phyllite, and sandstone or the Shimajiri clay is penetrated, because only low yields or

dry holes can be expected from these rocks. Loss of tools and breakage of equipment may be expected in the limestone which is cavernous. Caverns and fissures may also cause difficulty in maintaining circulation if rotary drills are used.

Map unit 2

Location and accessibility: Areas included within the delineation of Map Unit 2 include three on the Pacific Ocean side of the island between Ishikawa and the tip of Katchin-hantō and four on the East China Sea side from Zampa-misaki to the Asha-kawa (pl. 1). The only areas easily accessible to the Integrated Island Water System are those east of the Tengan Treatment Plant, in the vicinity of Yontan Treatment Plant, and north of the Asha-kawa. The other areas could probably be exploited only by villages and military installations independent of the Integrated Island Water System.

Geological conditions: Beds of porous, fissured, and cavernous limestone, which usually extend to depths below sea level and are bounded on one side by the ocean, comprise Map Unit 2. Water percolating downward and toward the sea may collect in caves, fissures, and porous layers well above sea level and emerge as springs on hillsides or at the base of cliffs. It may also continue downward to near sea level, where it is trapped against the denser salt water of the sea, to become part of the reservoir of basal water. This can happen only if the contact of the limestone, limy sand and gravel with the underlying impermeable Paleozoic metamorphic rocks or Shimajiri clay is below sea level. Reservoirs of basal water are known to exist under areas delineated as Map Unit 2. Basal water is that which saturates the rock at and below sea level. If the rate of discharge is greater than the rate of recharge, sea water will follow the withdrawal of fresh water and ruin the well. Wells such as W-6 tap water perched above the basal water and are not in danger of salt-water intrusion.

Springs: Numerous springs are located at the base of cliffs and on hillsides in Map Unit 2, but except for S-44, the spring near Kawasaki Pump Station, they are not shown on Plate 1. This spring yields more than 100,000 gpd. It drains into the Tengan-gawa and is used as a source for the Tengan Treatment Plant.

Wells: The wells at Yontan Treatment Plant (W-5) and near Sobe (W-6, W-7, and W-8) illustrate the type of ground-water conditions typical of Map Unit 2. Three of the wells obtain water from the basal-water reservoir, about 10 feet above to about 10 feet below sea level, and range in depth from 60 to 90 feet. The fourth well (W-6) is only 20 feet deep and taps perched water from a channel in limestone about 40 feet above sea level. The best producer is the Yontan well which supplies the Yontan Treatment Plant, but pumping must be controlled to keep within the limit of 75,000 gpd which is the point at which salt-water intrusion begins.

Well siting and drilling problems: The greatest number of sites for potential wells are in the areas west of Kadena Airbase, and southeast and south of Tengan Treatment Plant. Unless yields of perched water in solution channels above sea level are sufficient to meet needs, drilling should continue until the basal water at sea level is reached. Loss and breakage of tools in cavernous limestone are the greatest hazards. Maintenance of circulation for a rotary drill is also apt to

be a problem. After a well has been completed in a basal-water aquifer, pumping must be carefully controlled to guard against salt-water intrusion.

Map unit 3

Location and accessibility: Areas included within the delineation of Map Unit 3 are widespread and extensive, especially on Motobu-hantō, fringing the coast of the northern part of the island, north of Easley Treatment Plant, from Bolo peninsula to Katchin-hantō, southward along the East China Sea, and in the extreme southern and southeastern part of the island. Some springs and wells are near water plants and pipelines but much additional pipeline would be required to tie the potentially most useful springs, located in southern Okinawa, into the Integrated Island Water System. Almost all springs are utilized by the native population.

Geological conditions: Areas of limestone, in which ground water generally is perched inland but not along the shore, are included in Map Unit 3. The limestone of Paleozoic age is compact and crystalline whereas the limestone of Tertiary and Pleistocene age is a loosely cemented coralline and rubbly material containing, in places, limy sand and gravel. The Paleozoic limestone is restricted to northern Okinawa where it occurs on Motobu-hantō, on the west mainland, and at the northern tip of the island. Tertiary and Pleistocene limestone occurs extensively over the southern part of Okinawa and along the coast of the northern part of Okinawa. Water available to springs and wells is chiefly restricted to some fissures and caverns.

Drainage in these areas of karst is largely subsurface. Water tables above sea level and perched above zones of unsaturated rock are common. They develop in porous, permeable limestone underlain by thick masses of impermeable silty clay of the Shimajiri formation. In most places the perched water bodies are dynamic features which drain along the top of the clay in the form of underground streams and discharge at the surface as springs. Direction of flow is governed by the slope of the limestone and Shimajiri clay contact, and by the direction of faultlines where Shimajiri clay is brought up vertically against the limestone. Quantities are determined by the size of the limestone surface collecting the rainwater which then finds its way downward through cracks and solution cavities, and the number and length of interconnecting channels.

On Okinawa, traps capable of retaining permanent bodies of perched ground water result from the pattern of faulting in the southernmost part of the island. A series of intersecting high-angle or vertical faults cuts the southern end of the Nakagusuku anticline (which parallels the axis of the island) into a number of blocks, each of which is tilted up on the northern corner and down on the southern. Limestone in the southern corner of many of the fault blocks is at a lower level than the upfaulted silty clay, forming a structural trap. Many of the traps have been drained by the development of either underground or surface drainage. An underground lake at Itokazu is believed to occupy such a fault trap.

Springs: The greatest number of large springs discharge perched ground water. A few of the large springs exist at the mouths of caverns in limestone where underground streams issue forth. Many small springs

issue from scarcely more than cracks in the rocks, and others are merely seeps. Many villages and farming areas depend on springs for their water supply and almost every isolated paddy field has a spring nearby. Springs with small intermittent yields are too numerous to plot on Plate 1, Ground-Water Map. However, 67 springs are shown on the Ground-Water Map and described in Table 6 and most are located within the area of Map Unit 3.

Springs are extremely abundant in southern Okinawa. Five of the seven springs yielding 1,000,000 gpd or more, are in the Yoza-Mabuni-Chinen area where they drain considerable areas of limestone. The Mabuni spring (S-4) really consists of two springs located approximately 60 feet apart near the base of a sea cliff. Together they yield 4,000,000 gpd, but in dry weather this yield may drop as low as 1,000,000 gpd. They are located in the low corner of a tilted block of limestone which itself receives the overflow drainage of other tilted blocks. No use is made of the water principally because of the inaccessible position on the sea cliff. Yoza spring (S-3) which is tied into the Integrated Island Water System produces 1,500,000 gpd but may drop as low as 500,000 gpd. The spring (S-2) at Chinen Treatment Plant is the discharge of a long underground stream which draws from much of the Chinen plateau (pl. 6). Its yield has been measured at 2,088,000 gpd, but minimum yield has been known to be as low as 500,000 gpd. This spring originally was used by the natives for drinking and hydroelectric power. The Maedaira spring (S-1) produces 1,063,000 gpd and is used for general purposes in dry weather. High turbidity prevents its use after rains. The Mēgā spring (S-5) produces roughly 1,600,000 gpd and is used by the Okinawans for irrigation.

Among the large springs elsewhere in southern Okinawa are the other two of the seven yielding 1,000,000 gpd or more. One is south of Futema-gawa (S-6) and has a yield of as much as 1,293,000 gpd and used by the natives for drinking, and the other is the spring on the bank of the Bishi-gawa (S-7) which produces 1,000,000 gpd.

South of Mabuni another large spring (S-11) yields up to 900,000 gpd. This spring (pl. 7) flows to the sea from its location just above high-tide level and because of this location is not used.

Several large springs mark the emergence of underground streams which are continuations of surface streams that follow underground channels across limestone areas. Flow of such springs is increased by ground water from the limestone which may even make up the bulk of the dry-season flow. A large underground stream emerges as a spring (S-12) from a cave near the junction of Highways 1 and 30. Flow of this spring, which is one of the principal water points for the Naha City Treatment Plant, is about 504,000 gpd during the dry season when flow is maintained largely by water held within the limestone. During the wet periods the flow, of about 1,000,000 gpd, is largely from the rapid percolation of surface water into the limestone. A line of shafts (sinkholes, pl. 8) connecting the surface with subterranean drainage systems, and undrained depressions mark the underground channel connecting this spring and a long valley draining the limestone mass. Another large spring at the base of the sea cliffs west of Bolo Airfield is the discharge point of a perennial surface stream that follows an underground course across the airfield. Although some ground water is added to the spring discharge from the limestone, in this instance much comes from the surface stream.

Large springs also occur in northern Okinawa, although they are less common. A large spring on the north coast of Ii-shima (Ie-shima) drains perched ground water in limestone. Numerous small springs and seeps that have a large total flow occur on the steep slope above Tammya on the north shore of Shana-wan. In this region beds of Paleozoic limestone are broken (faulted) and thrust over other beds into a downward convex fold (syncline), the southern end of which has been removed by erosion. The springs occur where the trough of the syncline is exposed in a near vertical cliff and they represent the drainage of the entire block of limestone. A larger spring issues from the base of an exposure of Paleozoic limestone in the valley west of Wakukawa, on the north coast of Motobu-hantō. The spring flows at ground level, near the level of alluvial fill in the valley bottom. A small check dam diverts some of the flow into a pipe which carries water by gravity to Wakukawa. Springs also occur along the coast where Paleozoic limestone reaches the sea. Some of these springs are used by Okinawans as water sources.

The development of springs in the area of Map Unit 3 is more promising than the drilling of wells. Springs issuing from caves are most easily developed by the construction of low dams at or near the cave mouths to form pools from which water may be pumped. It is possible also to obtain limited underground storage by impounding the water in this way. Dams should not extend higher than the limestone contact since the permeable limestone will permit water to pass around the ends of the dam. A factor to be considered in building any dam is allowance for the greatly increased volume of water which flows after heavy rains. Underground streams exposed in sinkholes or caves may be treated as springs in their development, but water taken from such a stream will result in a decreased flow of the spring at the lower end of the watercourse.

Wells: Wells in Map Unit 3 have been developed primarily in southern Okinawa and usually tap perched water in underground channels or at the contact of the limestone with the underlying Shimajiri clay. The abundance of surface water in northern Okinawa precludes the development of wells except in those areas where only small quantities are needed and the surface supply is inaccessible.

Miwa-son well (W-9), FBIS well (W-12), and the well at Odo (W-33) all tap perched water in underground channels and range in depth from very shallow to 85 feet. They illustrate the great variability of yield of wells in this map unit. The yields are from about 10,000 to almost 1,000,000 gpd. Well W-12, yields 19,400 gpd at 50 feet above sea level while two test borings W-13, 63 feet above sea level and W-14, 33 feet below sea level, located nearby, are dry holes.

The well on Katchin-hantō west of Heshikiya (W-11), 80 feet deep and the Okinawa Motors shallow well (W-10), 37 feet deep, tap aquifers at the base of limestone. Yield is 40,000 gpd from W-11 and 10,000 gpd from W-10.

A large accumulation of basal water is known to underlie the eastern end of the island of Ie-shima and it may extend along the south coast to the west end. Of the 7 wells reported to have been drilled by the U. S. Navy Seabees, 2 produced fresh water, 3 produced salt water, and 2 silted up. The wells encountering salt water reportedly were drilled near the northeast corner of the island and may have been

Cavern on Chinen plateau formed in limestone. The stream has been dammed to form the pool of water. Photo by U. S. Army.

Komesu-Kaigan spring (S-11) in limestone just above high-tide level on southern coast of Okinawa. Yield is more than 900,000 gallons per day, but little use is made of the water. View south. March 1957.

Sinkhole in limestone of southern Okinawa. This feature is typical of areas of subsurface drainage. Photo by Okinawa Engineering District.

drilled too deep. The two producing fresh water, aided by a large spring, were able to supply the troop needs for the island.

Well siting and drilling problems: The success of well drilling depends on the fortuitous tapping of trunk channels fed by many tributary channels. Siting wells anywhere in limestone areas should take advantage of the fault systems. Drilling should cease as soon as the underlying Paleozoic schist, phyllite, and sandstone or the Shimajiri clay is penetrated. The chief drilling difficulties would be the loss of tools and breakage of equipment due to caverns and fissures. The caverns and fissures may also cause difficulty in maintaining circulation if rotary drills are used.

Map unit 4

Location and accessibility: Areas included within the delineation of Map Unit 4 are lowlands fringing the coast (pl. 1). Sites suitable for development are accessible chiefly to villages, Naha city, and small military installations located near the coast.

Geological conditions: Areas of beach deposits consisting of detrital limestone, sand, and gravel, and areas of alluvium in stream valleys are delineated as Map Unit 4. Thin lenses of fresh water at or near sea level rest over sea water in beach deposits. Fresh water in alluvium of flat-floored valleys may rest on impermeable rock or on permeable rock saturated with sea water near the coast. Danger from salt-water intrusion is not as great when recharge to the wells is mostly from the adjacent stream as when recharge is largely from fresh water over the sea water (fig. 4 and fig. 5).

Springs: Springs generally do not occur in the area of Map Unit 4. The permeability of the material and its low position along the coast both tend to encourage the absorption rather than the discharge of water.

Wells: Small native dug wells, a few feet in depth, are too numerous to record. Among the wells listed in Table 5, the following are representative of the area of Map Unit 4: W-15, W-16, and W-17. The Tsukazan well (W-15), about 12 feet in diameter, is an example of one of the larger village wells in stream alluvium. It is on the Nagadogawa a short distance upstream from Kokuba bay. The gallery well (W-16) is 200 feet long at sea level north of Nakatomari village and illustrates maximum production of fresh water from beach sand. If more than 100,000 gpd were taken from the well it probably would be ruined by the intrusion of salt water. The well (W-17) supplying the Ishikawa Treatment Plant is 10 feet deep, 10 feet long, and 4 feet wide. The maximum yield is 20,000 gpd of fresh water. Increased pumping would probably cause salt-water intrusion. During World War II, 7,200 gpd was taken from a 200-foot trench at Kuba, but 1,440 to 2,880 gpd per foot of trench was obtained on Katchin-hantō. On the other hand, an unsuccessful gallery well was made at Kuba-saki on the coast of Nakagusuku-wan. Deep-drilled wells such as those in the Naha city area draw their water from near or at the base of the Shimajiri formation and are not representative of the wells within Map Unit 4.

Well siting and drilling problems: The best sites for large-diameter dug wells and infiltration galleries are within a few hundred feet of the shore in coast deposits and in alluvium adjacent to streams near their mouths.

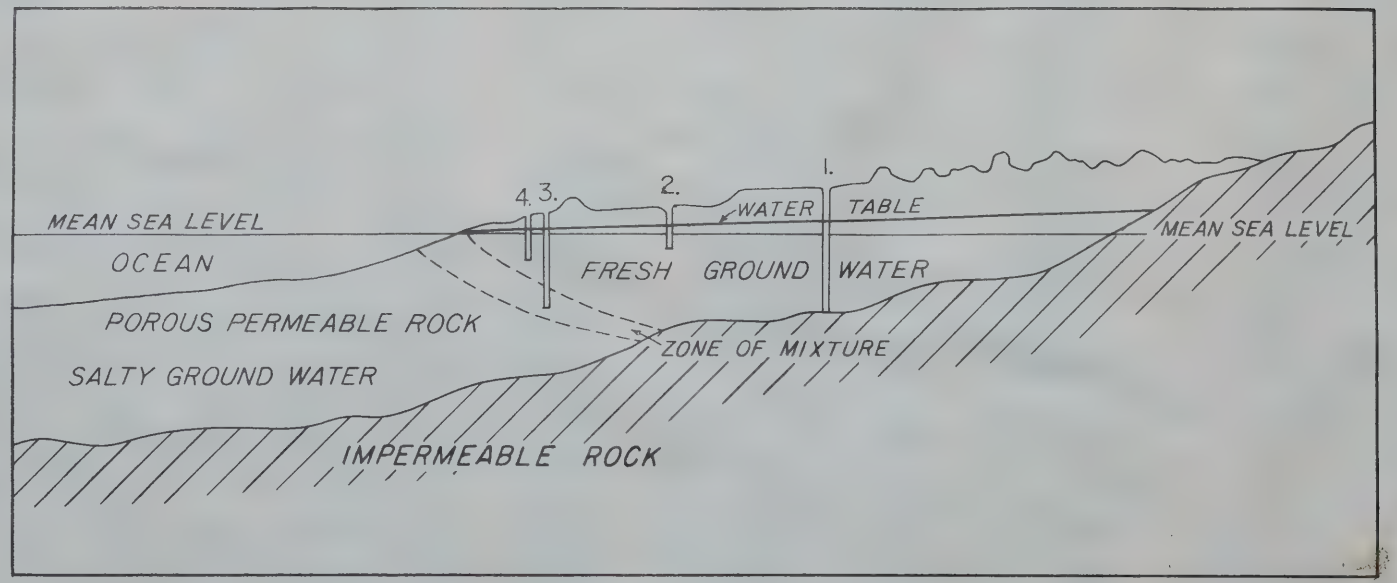

Figure 4. Development of wells in coastal areas. Water table is shown in nonpumping position. During pumping, cones of depression and inverted cones of salt-water intrusion are formed at wells. Well 1 would produce fresh water without danger of contamination by salt water; well 2 would also, unless pumped very heavily over a prolonged period. Well 3 penetrates the zone of mixture and so would produce salty water. Shallow well 4, although near well 3, would produce fresh water; however, well 4 would become contaminated by salt water if pumped heavily.

Fig. 5

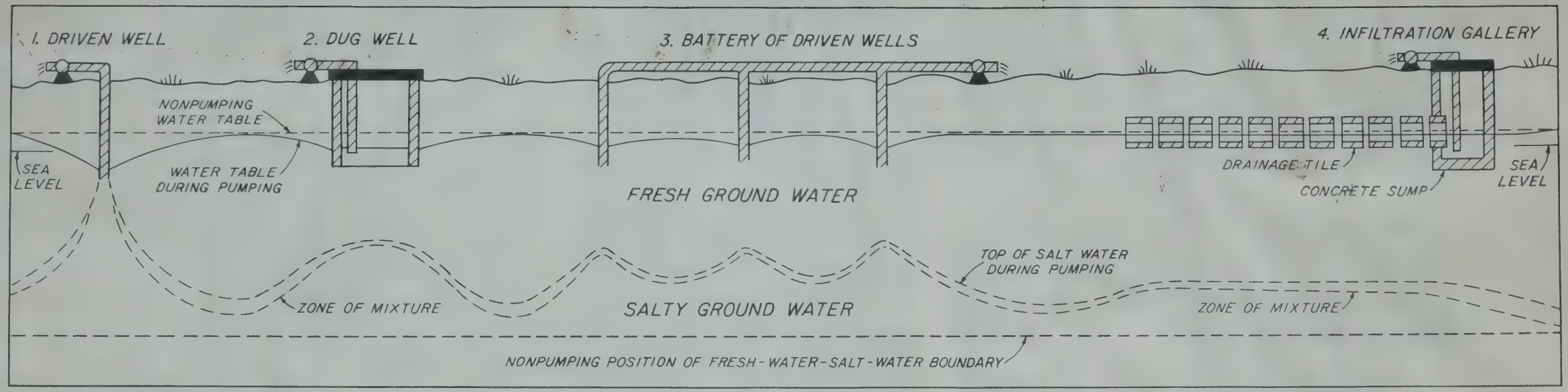

Figure 5. Development of ground-water supply in coastal areas. Excessive pumping in small areas results in contamination of water supply (1). Note that the rise of the salt water during pumping is many times the drawdown of the water table. Contamination can be avoided by distributing the pumpage over a larger area, thereby decreasing the drawdown and the rise of salt water at any one point. Pumpage can be distributed by using a large dug well (2), a battery of driven wells (3), or an infiltration gallery (4).

The gallery wells developed by the Seabees during World War II were made by ditching to just below mean sea level by means of a dragline or clamshell bucket. The length of the ditch depended on the permeability of the material encountered and the amount of water desired. The ditch was graded to slope gently to a central sump. In the bottom of the ditch a row of oil drums with the ends removed and the sides perforated were placed to lead water to the central sump which was lined either with concrete or metal. Crushed limestone was placed around and over the drums and the whole was backfilled. Oil drums were used merely because they were handy. Large drain tiles, perforated sheet-metal culverts, or any other type of pipe of large diameter could have been used in place of the perforated oil drums. The rate of flow of all wells should be carefully controlled to guard against salt-water intrusion.

Map unit 5

Location and accessibility: Areas included within the delineation of Map Unit 5 are very extensive throughout southern Okinawa from Katchinhantō southwestward (pl. 1). The areas are fringed on the east chiefly by coastal deposits and on the west and south by limestone. Water from the base of the Shimajiri formation around Kokuba bay and along the pipeline extending northward from Yuza Treatment Plant is easily accessible to Naha city.

Geological conditions: The Shimajiri formation is largely a compact impermeable clay with beds of silty sand in places. Coarse sand and gravel occur at the base where the formation rests presumably on the Paleozoic rocks of Map Unit 6. Thickness of the Shimajiri varies from about 250 feet at the head of Kokuba bay to more than 4,000 feet near Yonabaru. This vast relief of the old Paleozoic surface on which the Shimajiri rests is due to erosion before the Shimajiri sediments were deposited and to faulting after the Shimajiri was laid down. The clay is the source rock for the natural gas from whence it migrated to permeable sand and gravel. The salt water associated with the gas probably is sea water trapped while the sediments of the Shimajiri were being deposited and which has not yet been flushed out of the formation by rainwater falling on the present land surface. The presence of gas and brackish water in some wells and fresh water free from gas in other wells also producing from the bottom sand and gravel indicates structural traps caused by faulting, which could probably be mapped by geophysical methods.

Springs: Springs in areas of the Shimajiri formation generally are associated with the boundary of limestone formations younger or stratigraphically above the Shimajiri. Water flowing in underground courses or moving through the porous beds within the limestone drains along the top of the compact clay and discharges at the surface as springs. The slope of the limestone and compact clay contact and the direction of faultlines where limestone is brought up against the Shimajiri clay determines the direction of flow.

Small springs or seeps which belong wholly to the Shimajiri formation are restricted to local areas where beds of silty sand or volcanic-ash deposits appear at the surface.

Springs are developed only locally by the natives. The water is used primarily for domestic purposes and irrigation.

Wells: All holes dug or drilled in the compact clay have been dry. A dry hole (W-29) was drilled at Shimabaku to a depth of 680 feet. Drilling ceased in Shimajiri blue clay. The only water found was a small amount at a depth of 80 feet at the base of the overlying limestone. A well drilled at an elevation of 117 feet near the tip of Katchin-hantō to a depth of 2,250 feet in the Shimajiri failed to produce water or to reach the base of the Shimajiri. Another well near Yonabaru at an elevation of 119 feet also failed to produce water or reach the base of the formation at a depth of 4,036 feet.

Only wells reaching beds of silt or fine sand within the formation or beds of sand and gravel at or near the base of the Shimajiri produce water. A well drilled west of Awase-hantō yielded 4,000 to 10,000 gpd from silt beds about 50 feet below sea level. Two pits dug during World War II, each about 25 feet deep and 10 feet wide in silty beds at Naha produced about 21,000 gpd. A single smaller well, also near Naha, was reported to yield about 30,000 gpd. Two test wells (W-18) at Naha Airbase are reported to have yielded 39,000 gpd each from silt at depths of 165 feet and 200 feet. The fresh water was 65 to 100 feet below sea level.

The Catholic Mission well (W-19) at Shuri that was drilled recently to a depth of 265 feet in silt probably will not yield over 14,000 gpd.

Brackish water and natural gas are produced from wells W-20, W-21, W-22, and W-23. The well (W-20) at Yakena on Katchin-hantō, which has a 1 1/2-inch casing yields 18,720 gpd and natural gas from black sand at 300 feet depth. The Kanegusuku well (W-21) near Itoman yields brackish water from sand at a depth of 550 feet. The Sugar Mill well (W-22) at Kaneku near the south end of the Yonabaru Airfield yields natural gas and 115,000 gpd of brackish water from sand at a depth of 700 feet. The Kokuei Kan Theater well (W-23) at Naha yields at least 200,000 gpd and natural gas from coarse sand at a depth of 586 feet. Water is too brackish for drinking.

Water reportedly good for drinking is produced from W-24, W-25, W-26, W-27, and W-28. North of the Naha City Treatment Plant, 100,000 gpd of reportedly good drinking water has been produced from Shimajiri sand at 500 feet in the Okinawa Motors well (W-24). Four wells (W-25, W-26, W-27, and W-28) near Naha to the southeast, draw drinking water from sand and gravel at the base of the Shimajiri at depths of 250 to 468 feet. Unlike the other deep wells, these four wells do not require airlift pumps. Two, W-27 and W-28, are flowing artesian wells.

Well siting and drilling problems: Large-diameter dug wells are easy to site and develop where silty and sandy beds crop out at the base of valley walls. Deep wells are easy to develop with rotary rigs. Siting of the deep wells is the major problem, because of complicated subsurface geology. Most places in the Shimajiri are unsuitable for deep wells. However, the occurrence of good wells in the Naha city area indicates that a systematic program of test drilling would be feasible here. Drilling should be carefully watched and logs should be detailed so that horizons may be identified and correlated. This is required for the mapping on the surface on which the aquifers at the base of the Shimajiri rests so that positions of brackish water and gas can be delineated from the positions of fresh water. The best places to start test drilling are at the margin of the alluvium or at the base of the uplands at the head of Kokuba bay and in the vicinity of the Sake Mill

well at the junction of Highways 3 and 68. The test drilling program may very well be conducted in conjunction with a geophysical survey.

Map unit 6.

Location and accessibility: Areas included within the delineation of Map Unit 6 are all north of the Bishi-gawa and Tengan Treatment Plant. The areas are fringed chiefly by limestone and gravel. Sites would be inaccessible except to small installations.

Geological conditions: Most of northern Okinawa is composed of phyllite, schist, sandstone, and related rocks of Paleozoic age. They are the oldest rocks of Okinawa and except for Shimajiri clay are the least permeable. Their generally low permeability and porosity limit the amount of water that can be obtained in most places. Where the rocks are badly fractured and broken, the creviced and porous zones are saturated with fresh water. The elevation of the water table throughout the area of Map Unit 6 (pl. 1) is at or slightly above the level of water in nearby permanent streams. Between streams the water table is higher, following the contour of the land, rising under hills and falling to stream level in the valleys.

Springs: Surface water seeps downward through the base of the soil through cracks and crevices and collects most abundantly in zones of severest fracture. Some of the water issues as springs on hillsides and cliffs. Yields are variable, but are subject to severe seasonal fluctuation. Most springs are not developed because of their general inaccessibility and the abundance of surface-water supply in the area.

Wells: Water in the fracture zones can be obtained by drilling wells. The Yakata well (W-30) and Tengan well (W-31) are representative of this map unit. The Yakata well, 164 feet deep, produced 8,750 gpd of moderately hard, very corrosive water from Paleozoic schist. The Tengan well, 155 feet deep, produced 34,500 gpd of moderately hard, very corrosive water also from Paleozoic schist.

Well siting and drilling problems: Because less than 10,000 gpd can generally be expected from single wells not more than 160 feet deep, areas of Paleozoic nonlimestone rocks are not recommended for well development. If it is necessary to develop wells for small quantities of water in places where surface streams are inaccessible the wells should be sited in the zones of severest fracture, otherwise yields would be negligible. This would require a geological reconnaissance. Bedrock would present few drilling problems.

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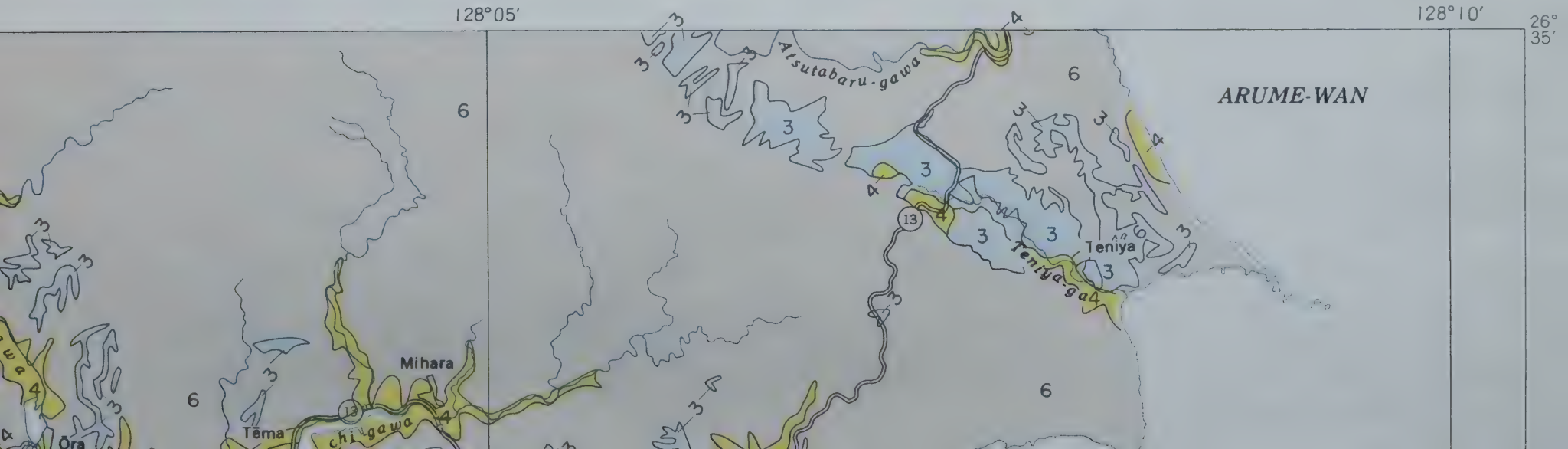

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